GODDARD & GODDARD ENGINEERING

Environmental Studies

STATE OF HAWAII GEOTHERMAL ACTION PLAN
ELEMENT III PART II
MICROMETEOROLOGICAL AEROMETRIC AND HEALTH EFFECTS ANALYSIS

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ELEMENT III

PART II

STATE OF HAWAII

GEOTHERMAL ACTION PLAN

MICROMETEOROLOGICAL AEROMETRIC AND HEALTH EFFECTS ANALYSIS

CONTRIBUTION TO THE

INDEPENDENT AIR AND NOISE MONITORING PROGRAM REVIEW

CONCERNING THE JUNE 12, 13 AND 14, 1991 UNCONTROLLED VENTING

OF THE PUNA GEOTHERMAL VENTURES KS8 GEOTHERMAL WELL

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ELEMENT III PART I AND PART II REPORTS INTEGRATION

The Element III report contains Part I, Independent Air and Noise Program Review of Concerning the June 1991 Uncontrolled Venting of the Puna Geothermal Ventures KS-8 Geothermal Well, prepared by Robert L. Reynolds, Chairman Element III review committee, Air Pollution Control Officer (APCO) and Noise Control Officer, Lake County Air Quality Management District, Lakeport, California; and Part II of Element III, State of Hawaii Geothermal Action Plan Micrometeorological Aerometric and Health Effects Analysis, prepared by Wilson B. Goddard, Ph.D., Principal, Goddard & Goddard Engineering - Environmental Studies, Lucerne, California. The Part I and Part II reports are in full agreement as to the major findings and recommendations.

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ELEMENT III PART II

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ES 1.0 EXECUTIVE SUMMARY OF FINDINGS AND RECOMMENDATIONS

A micrometeorological aerometric analysis has been conducted on the uncontrolled Puna Geothermal Ventures (PGV) injection well uncontrolled venting starting at 2319 hrs on June 12, 1991 and ending at 1200 hrs on June 14, 1991. The purpose of this study is to provide independent verification of monitoring and spot measurements of ambient concentrations of hydrogen sulfide (H2S) as well as provide estimates of plume concentration and plume transport paths in areas where documented health effects occurred.

ES 2.0 SUMMARY OF FINDINGS

- o Independent estimates of hydrogen sulfide (H2S) ambient concentrations were shown to be in substantial agreement with local monitoring station and mobile spot measurements throughout the venting period.
- o Local H2S concentrations were elevated above health significance levels and correlated with health complaints.
- o Regional H2S transport of the KS8 venting plume cloud was documented by visual sighting, by regional and local wind assessments, and by the chronology and position of health complaints beyond 10 miles (16 km).
- o Estimates of the emissions of other air toxics and estimates of the impacts are shown to be of significant health concern.
- o The permittee is in apparent violation of permit requirements for H2S emission limits, for H2S air quality impacts, for exceeding noise limits in duration and in magnitude, has not utilized the Best Available Control Technologies and has not utilized equipment described in the Authority to Construct.

ES 3.0 SUMMARY OF RECOMMENDATIONS

It is recommended that PGV pay for any additional expense involved in implementing the following measures:

1. Emissions limits for H2S be enforced by DOH personnel.

2. A Puna Air Monitoring Program (PAMP) be formed and managed by DOH with participation by the developer, the local agencies, State agencies, local concerned organizations and local concerned residents. An Operational Management of Air Resources (OMAR) type system be established to link all PAMP stations to a central computer to which an emergency response system is linked. The central computer should archive monitoring data and allow near real-time access to data for air management activities by the developer, by responsible agencies and by local community groups.

3. Modify station positions and install additional meteorological monitoring equipment and sites to further study the geothermal air pollution meteorology of the location and zone of impact.

4. The PAMP committee manage local and regional air transport special studies.

5. The PAMP committee should quality assure monitoring data, document all quality assurance procedures and publish sufficient volumes of the monitoring documents and special studies so that developers, engineers and environmental scientists have access to the documents.

1.0 INTRODUCTION

A micrometeorological aerometric analysis has been conducted on the Puna Geothermal Ventures (PGV) injection well uncontrolled venting starting at 2319 hrs on June 12, 1991 and ending at 1200 hrs on June 14, 1991. The purpose of this study is to provide independent verification of monitoring and spot measurements of ambient concentrations of hydrogen sulfide (H2S) and other air toxics as well as provide estimates of plume concentration and plume transport paths in areas where documented health effects occurred.

The uncontrolled venting incident at the KS8 well released an estimated 200,000 lb/hr (95,300 kg/hr) of steam and brine containing 180 lb/hr (81.7 kg/hr) of H2S in a complex plume cloud which was estimated to have emissions extending from ground level to a height of 65 ft (19.8 m). An estimate of the emissions of air toxics is contained in Table 1-1. The estimates in Table 1-1 are based upon wells KS-3 and KS-1A recent well chemistry and on Table 4-4 of the March 1989 PGV Authority to Construct.

TABLE 1-1

ESTIMATED EMISSIONS OF AIR TOXICS

RELEASED DURING THE KS8 UNCONTROLLED VENTING

Estimates based upon a steam flow rate of 210,000 lb/hr using geochemical data from KS-3, KS-1A and Authority to Construct.

Component	Emission Rate	
	lb/hr	kg/hr
Hydrogen sulfide	180	81.7
Lead	13.6	6.16
Nickel	1.80	0.817
Chromium	1.44	0.654
Manganese	2.36	1.07
Copper	0.326	0.148
Zinc	0.384	0.174
Arsenic	0.008	0.004
Mercury	0.001	0.0005
Silicon Oxide	30.0	13.6
Total Dissolved Solids	700	318

Note:
Estimated worst case 100% flash;
Table 4-4, page 4-10, March 1989 AtC

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2.0 STUDY METHODOLOGY

The methodology of the micrometeorological aerometric analysis utilizes the Micrometeorological Air Dispersion Assessment Methodology (MADAM) which follows guidelines established by regulatory agencies for air quality impact analysis (Appendix A).

Information characterizing the KS8 emissions and the initial plume rise were obtained from Robert L. Reynolds' on-site assessment, the PGV emission estimates, and from photographs and videos of the well emissions. Meteorological data from the Southwest, Alvarez and Wade monitoring sites were used to estimate the initial wind speed, wind direction, standard deviation of wind direction (sigma), air temperature, relative humidity and precipitation.

The distribution of atmospheric pollutants from their sources to the receptor areas, and their paths of travel and concentration, are dependent upon the wind flow regime and upon the pollutants' vertical and horizontal dispersion. The dispersion of atmospheric pollutants both vertically and horizontally is dependent upon the state of atmospheric stability:

- **unstable** atmospheric conditions [temperature decreasing with height at a rate **greater** than the adiabatic lapse rate of 5.4 °F/1,000 feet (1 °C/100 meters)] greatly **enhance** dispersion;

- **stable** atmospheric conditions [temperature decreasing with height at a rate **less** than the adiabatic lapse rate] greatly **diminish** dispersion.

Unstable conditions prevail during the afternoon periods, while stable conditions occur at night and in the early morning hours. Stable conditions aloft, called temperature inversions, tend to cap upward dispersion of pollutants.

The estimation of air quality impacts follows procedures recommended by the Environmental Protection Agency (EPA) (Goddard, 1986 and 1987). Errors are estimated and presented as ± values which indicate that there is a 68% probability that values will lie within these limits. Atmospheric Stability Classifications A through F are used where A is extremely unstable, D is neutral and F is moderately stable.

Hydrogen sulfide is considered the most critical air pollutant contained in the geothermal resource emissions. Other gaseous and small particulate pollutants discussed will disperse similarly and will be compared to the estimates made for hydrogen sulfide (H_2S). The air quality impact analysis estimates are compared to the monitoring data from the Southeast, Southwest, Wade, Alvarez and Irvine stations, and to spot measurements taken throughout the event period.

The uncertainty in each estimated plume isopleth concentration is proportional to the concentration and will average 50%. This is the nature of turbulent transport. Tables of estimated concentrations contain uncertainty estimates.

The health effects of the toxic pollutant emissions are discussed in Section 4 and compared to referenced literature. The results of complaint surveys and the type of health effect are discussed. Many groups and individuals assisted on circulating, collating and compiling the health survey information.

The hydrogen sulfide air quality impacts are discussed in terms of the U.S. Occupational Safety and Health Agency (OSHA) 10 ppm worker Permissible Exposure Limit (PEL) (Threshold Limit Value), the 15 ppm Short Term Exposure Limit (SPEL) (10 minutes per 8 hour) and the 50 ppm Ceiling Limit. In the absence of a State of Hawaii H2S Ambient Air Quality Standard (AAQS), the H2S OSHA standard of 10 ppm is divided by 4.2 (168 hour per week exposure / 40 hour worker week) times 100 (accounts for documented adverse health effects at the PEL (TLV) OSHA standard thus requiring additional protection for those which are more sensitive such as children and older persons) = 420. This equates for H2S to 10 ppm / 420 = 24 ppb (34 ug/m3) suggested health safety limit for the general public.

3.0 AIR QUALITY IMPACT ANALYSIS

The H2S measurements made at the monitoring stations and spot measurements made by personnel during the event were compared to air quality impact estimates. Meteorological data from the Wade Station, the Southwest PGV station and the Alvarez station were used in determining the local micrometeorological conditions. Winds along the coast were obtained from the National Weather Service station at the U.S. Coast Guard Reservation at Cape Kumukahi. The estimates of emissions listed in Table 1-1 were used in the impact analysis.

3.1 METEOROLOGICAL CONDITIONS DURING THE EVENT

During the first hour of the event which started at 2319 hrs on June 12, 1991, the winds were from the north-northwest, 330 deg at 6.25 mph (2.79 mps) at the SW station (ending time of 0000 hrs). The wind speed remained fairly uniform with a low of 4.73 mph (2.11 mps) at 0400 hrs on June 13, 1991. Wind directions remained out of the northwest sector until 1000 hrs when the trade wind influence shifted the direction into the north-northeast sector.

The trade wind influence continued throughout the afternoon and evening with increasing wind speed peaking at 13.4 mph (5.96 mps) at the hour ending at 1300 hrs. Evening winds decreased in speed with a return of north-northwest winds briefly occurring at the hour ending at 2300 hrs. At that time at the SW station the winds were from 350 deg at 5.49 mph (2.45 mps). Low wind speeds persisted throughout the early morning hours of June 14, 1991 with a low of 3.88 mph (1.79 mps) again from the north-northeast sector.

Data on coastal winds was obtained from the U.S. Coast Guard Reservation at Cape Kumukahi, 6 miles (10 km) to the northeast of the event. Along the coast, the winds were from the north-northwest during the first seven hours of the event at 12 mph (10 knots). At 0700 hrs, the coastal winds became northerly increasing to 16 mph (14 knots) through the day and decreasing at night to a minimum of 9 mph (8 knots) by midnight.

Ambient temperature at the beginning of the event was 66 deg F (19 deg C) and the relative humidity was 88%. Dew or mist deposition occurred periodically at 0.25 mm (0.01 in) per hour. A drizzle occurred between 2200 hrs and 2300 hrs on June 13, 1991 which resulted in 2.57 mm (0.10 in) peaking between 0100 and 0200 hrs on June 14, 1991 at 11 mm (0.43 in) of precipitation. From 0200 hrs onward, no further dew or drizzle was indicated in the monitoring records.

All stations were used in the local and regional transport analysis. The Wade, Alvarez and SW stations' wind speed, wind direction and sigma were used. The SW station was used for initial local plume dispersion assessments since it was the closest station to the release site. The rolling and pocketed nature of the site and the prominence and proximity of craters and volcanic cones result in wind flow (orographic) differences between stations in both wind speed and direction.

Each local estimate of impact used the extremes in wind direction and sigma, and is shown as a range on the impact figures. The standard deviation of the horizontal wind direction (sigma) was used to estimate the outer bounds of plume movement. One half of the sigma was added to the outer boundaries of direction which indicates a 68% probability that the plume centerline will be confined within these boundaries.

Each station exhibited high sigma values which are attributed to the gustiness and meandering nature of the wind flow. The high humidity and presence of dew and drizzle are indicative of micrometeorological conditions at night that are slightly stable, Pasquil Stability Class E. During the day the conditions were estimated to be slightly unstable, Pasquil Stability Class C. Neutral conditions, Pasquil Stability Class D, were estimated to occur in the morning and in the early evening.

The meteorological conditions during the event were not "worst case" poor air dispersion. Using Figure 3-1, the frequency of annual nighttime wind directions, the conditions would be expected to occur about 3 to 4% of the time. The highest directional occurrence at night is winds from the west sector. During the daytime hours, Figure 3-2 indicates that the conditions would occur 3% of the time except for the period when the trade conditions prevailed which is the highest occurrence event with a frequency of over 6%. Wind speeds could have been very low or calm which would have increased proportionally the severity of the impacts.

3.2 LOCAL AIR QUALITY IMPACT ASSESSMENT

The results of the comparison for near-site air quality impacts are shown in Figures 3-3 through 3-16. The outer plume lines denote the plume transport direction plus half the wind direction standard deviation (sigma). The outer plume lines indicate where meanders of plume direction may stray at the 68% probability level. The estimated isopleths of H2S concentration are shown on the figures for 500 ppbv, 100 ppbv, 50 ppbv and 25 ppbv. Each isopleth extends 1.0 mile (1.6 km) from the source.

The square brackets, [25 ppb] for example, indicate a monitoring site or a mobile measurement. The isopleth values are shown with the units below the number. The isopleths are based upon hourly averages since this more nearly conforms to ambient air quality standards. The estimated plume centerline concentrations are indicated by arrows. The nature of turbulent air transport gives rise to plume meanders and looping. The outer bounds of the estimated plume position indicate where the plume may stray. Within the indicated delineated boundary, the isopleths of concentration can and will move throughout the area with the upwind source area fixed.

The relationship of estimated plume position and estimated plume ground level H2S concentration are in agreement with the monitoring stations and the spot measurements. The relative width of the plume out to the 25 ppbv isopleth is narrow enough that it is usual that during emergency events many fixed or mobile monitoring sites miss the event or underestimate the impacts.

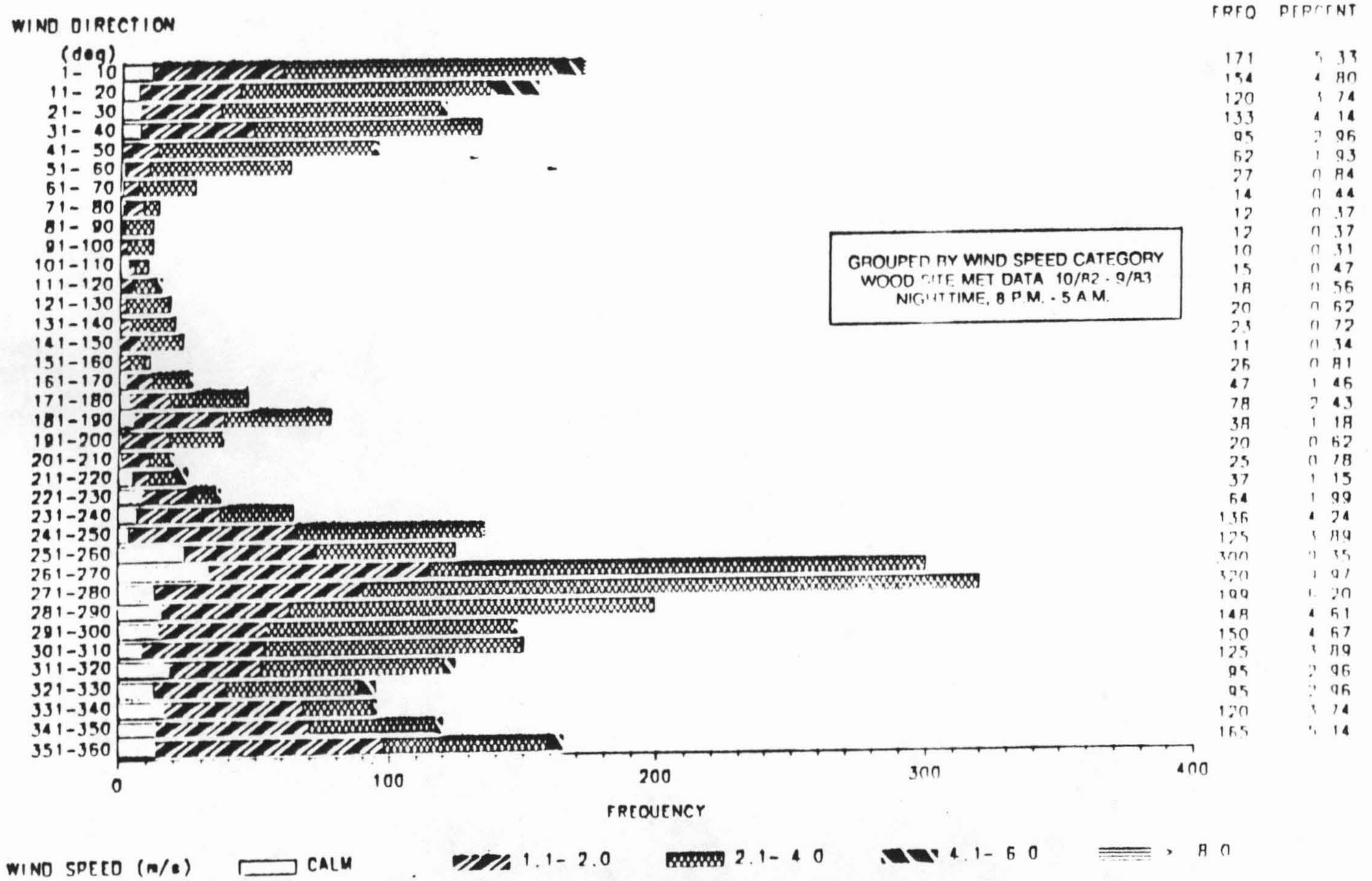

FIGURE 3-1 FREQUENCY OF ANNUAL NIGHTIME WIND DIRECTIONS

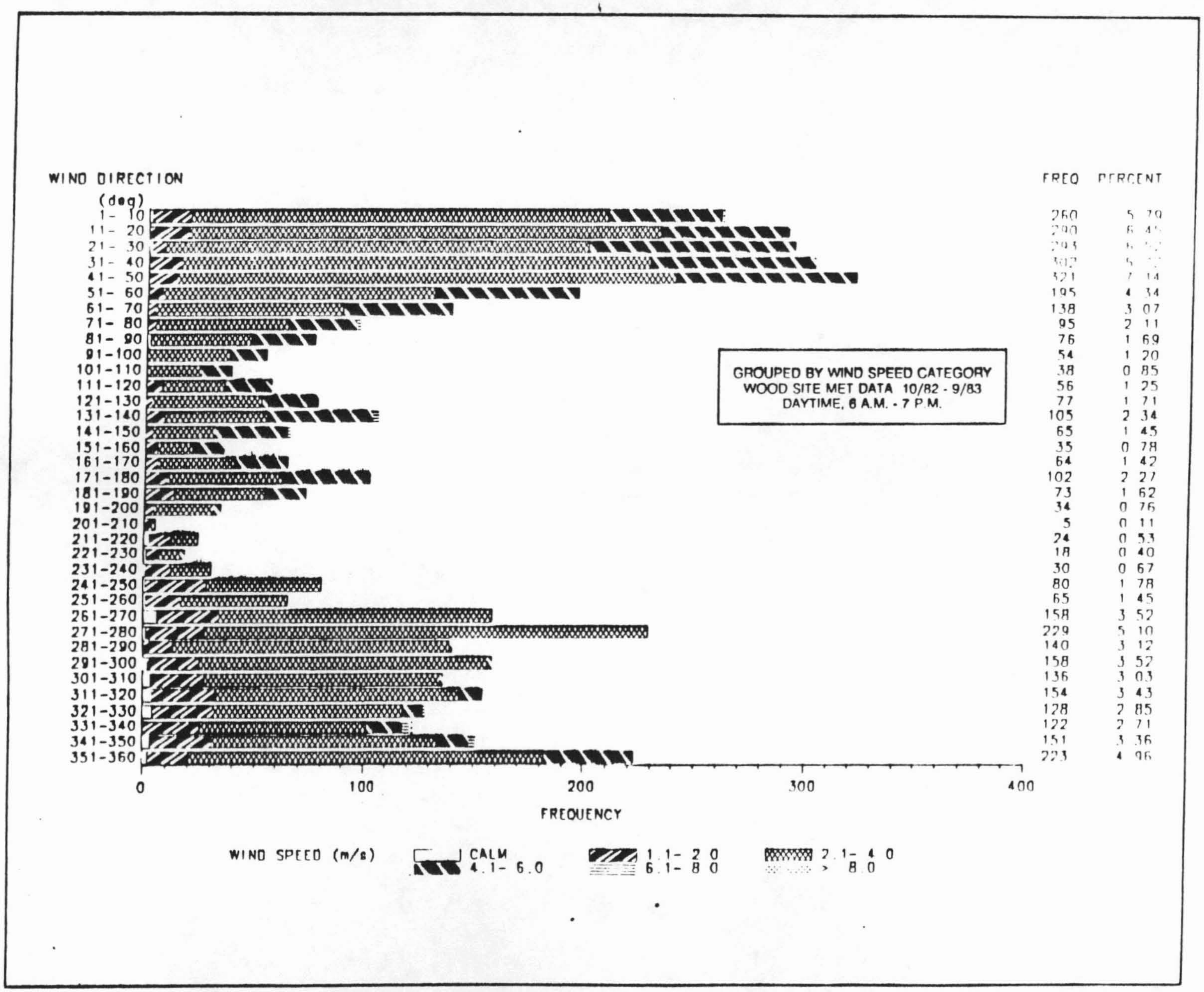

FIGURE 3-2 FREQUENCY OF ANNUAL DAYTIME WIND DIRECTIONS

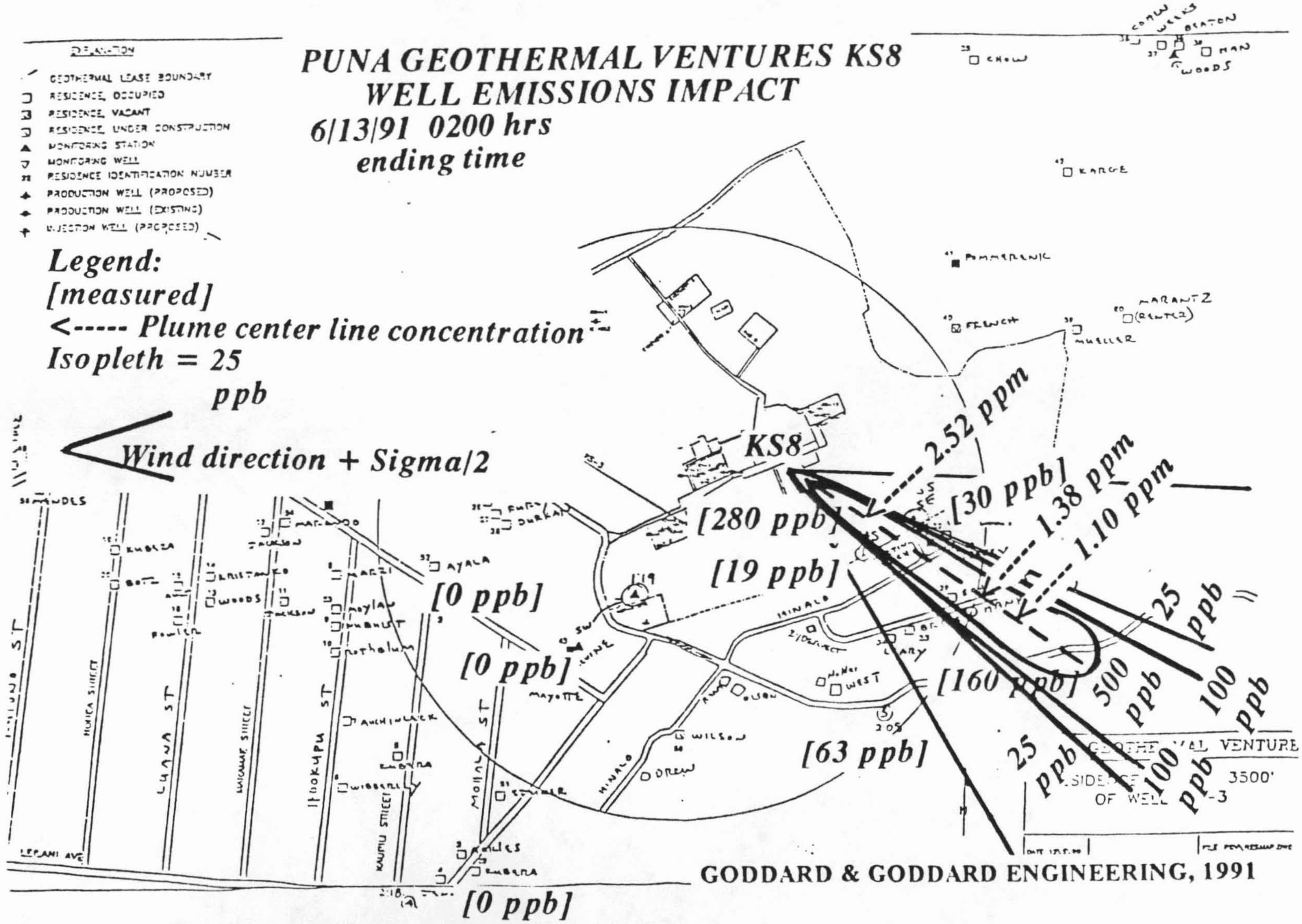

FIGURE 3-3 PGV KS8 WELL VENTING 0100 TO 0200 HOURS
JUNE 13, 1991 LOCAL IMPACT

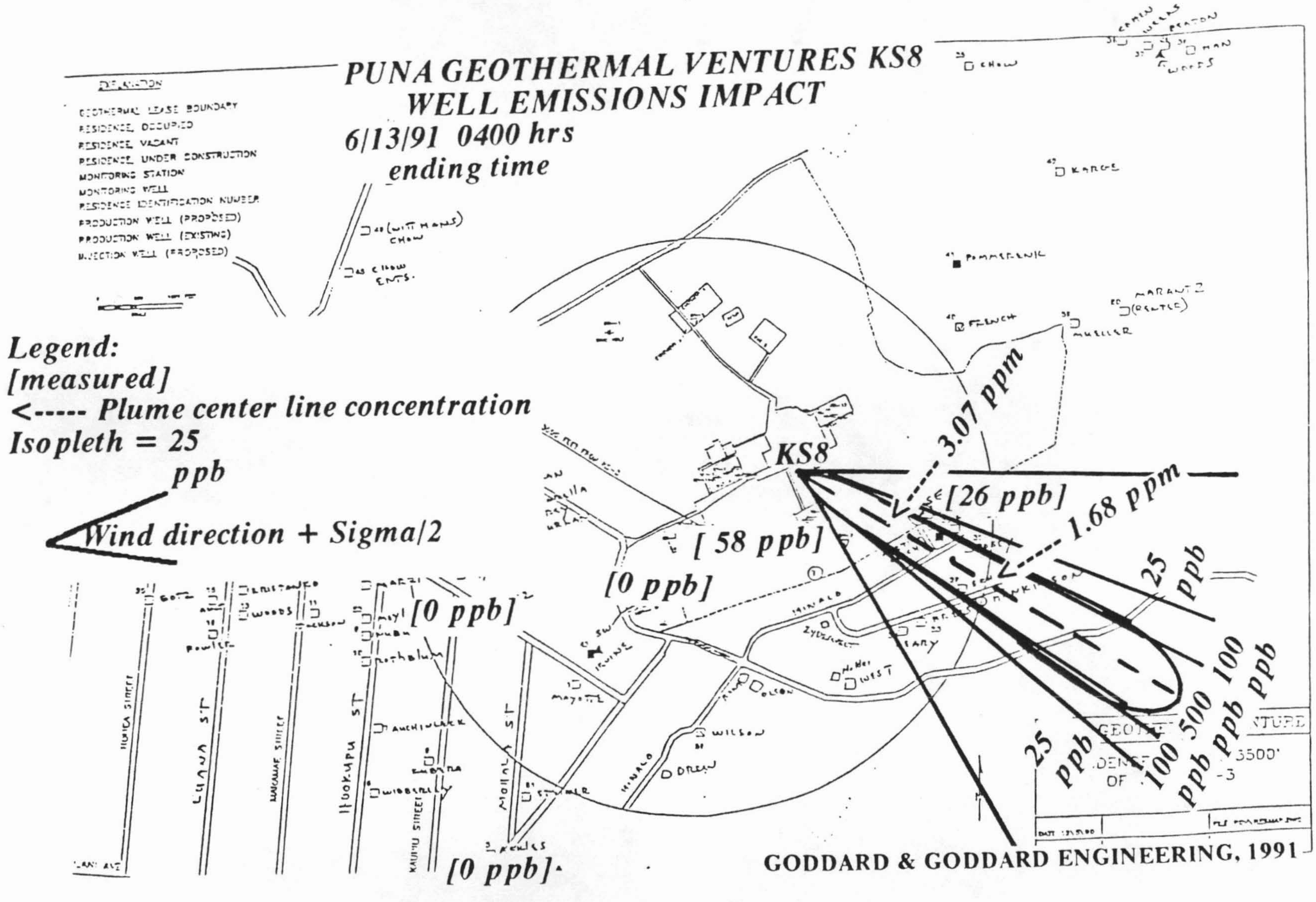

FIGURE 3-4 PGV KS8 WELL VENTING 0300 TO 0400 HOURS
JUNE 13, 1991 LOCAL IMPACT

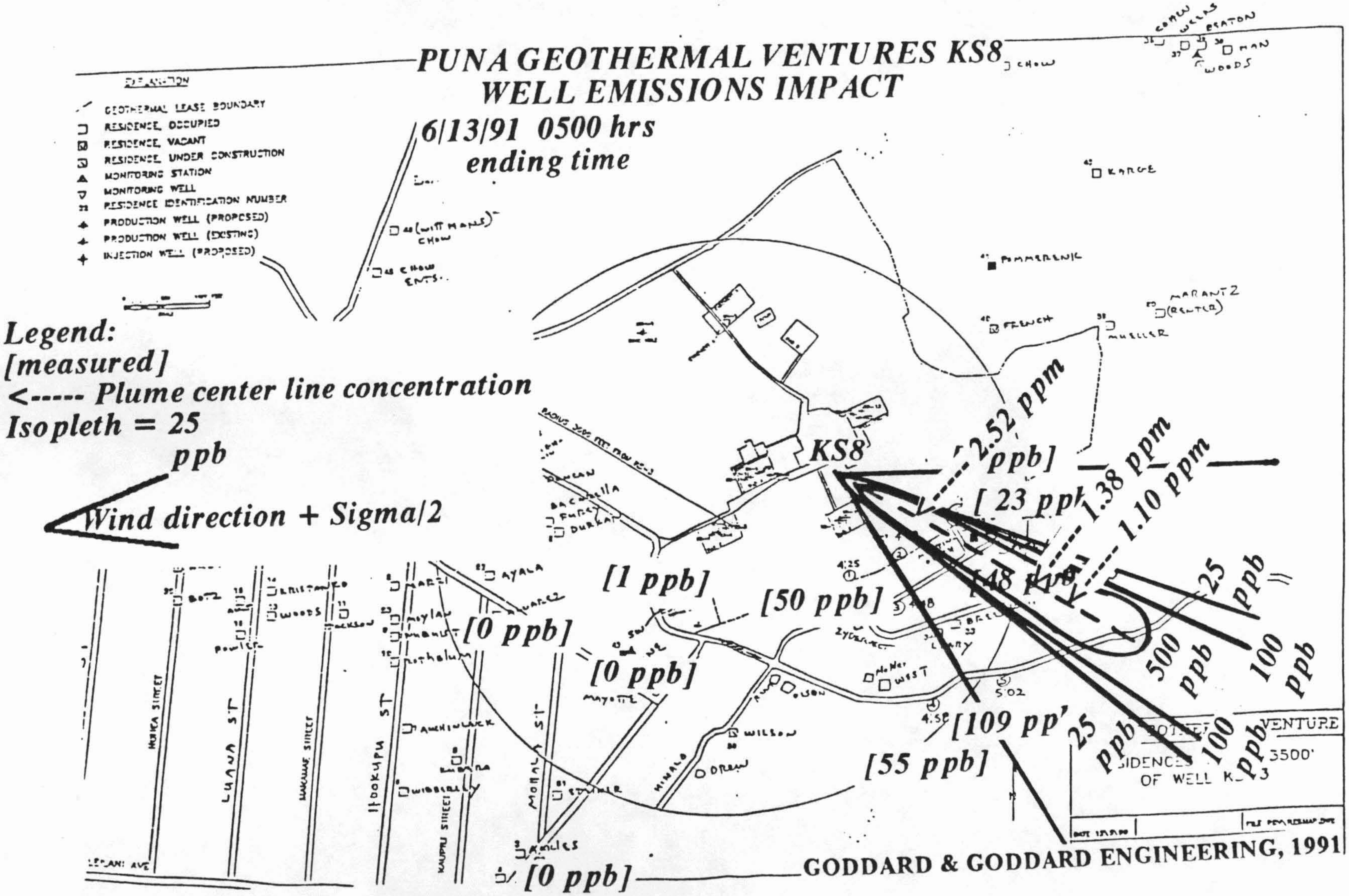

FIGURE 3-5 PGV KS8 WELL VENTING 0400 TO 0500 HOURS
JUNE 13, 1991 LOCAL IMPACT

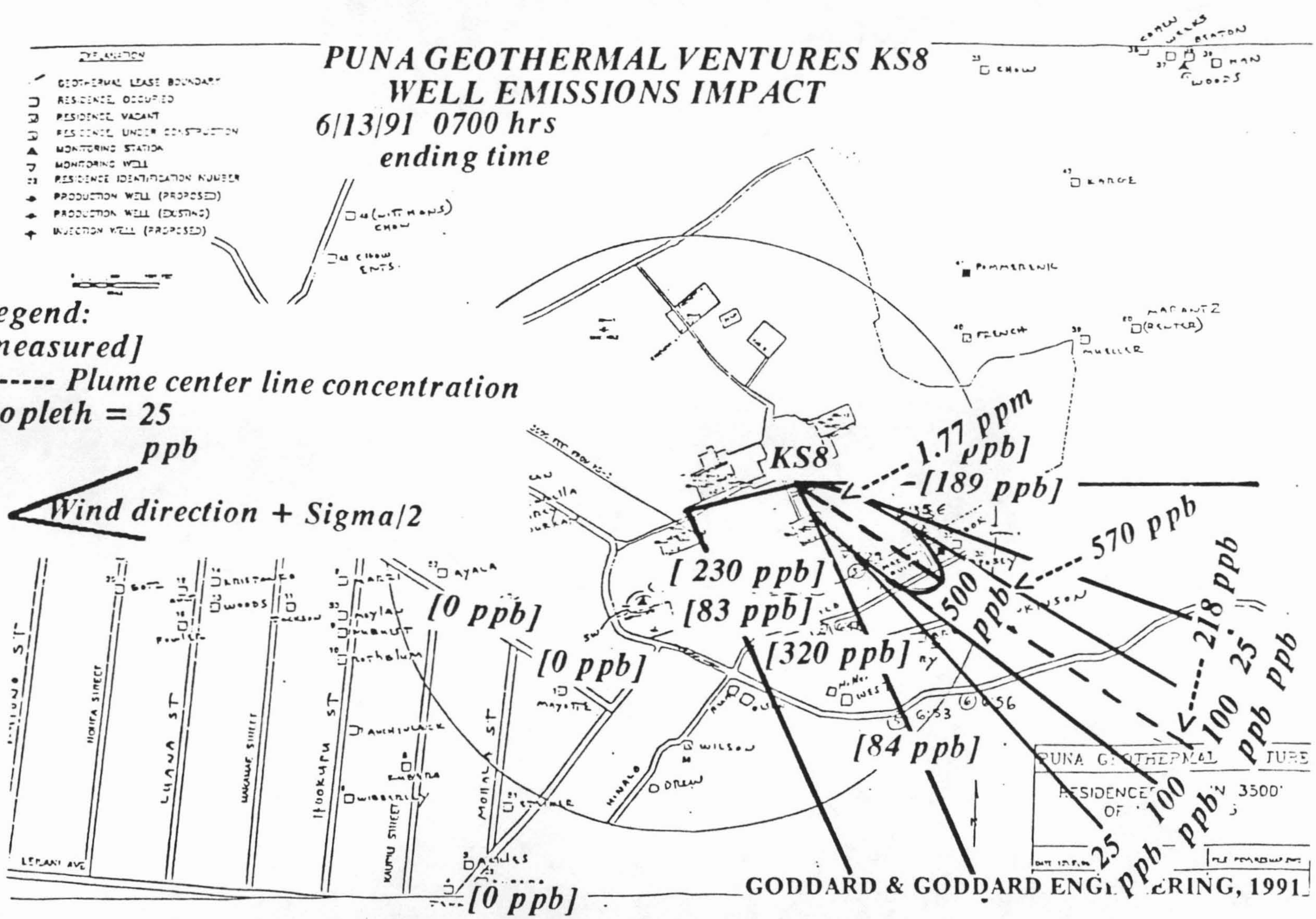

FIGURE 3-6 PGV KS8 WELL VENTING 0600 TO 0700 HOURS
JUNE 13, 1991 LOCAL IMPACT

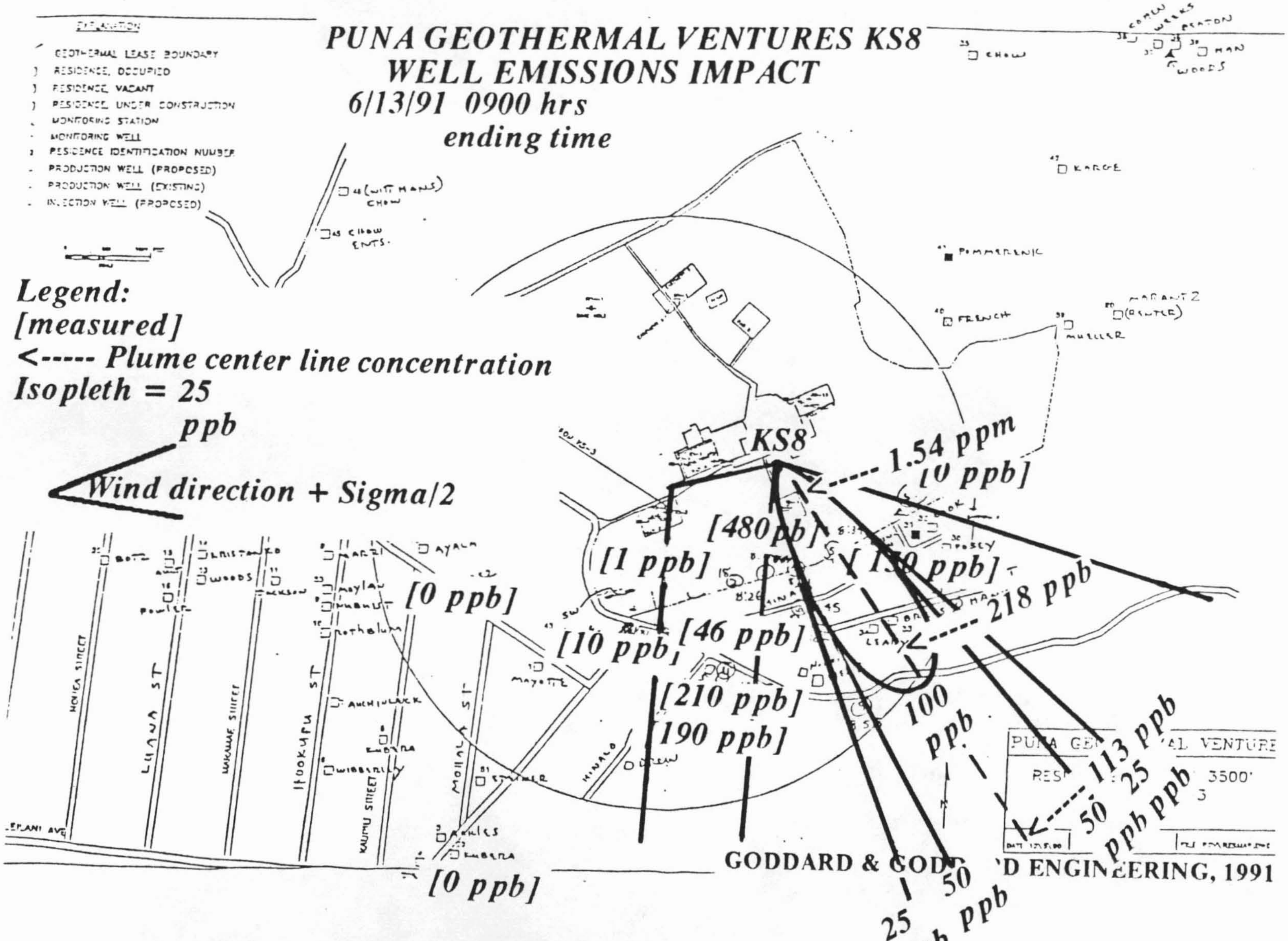

FIGURE 3-7 PGV KS8 WELL VENTING 0800 TO 0900 HOURS
JUNE 13, 1991 LOCAL IMPACT

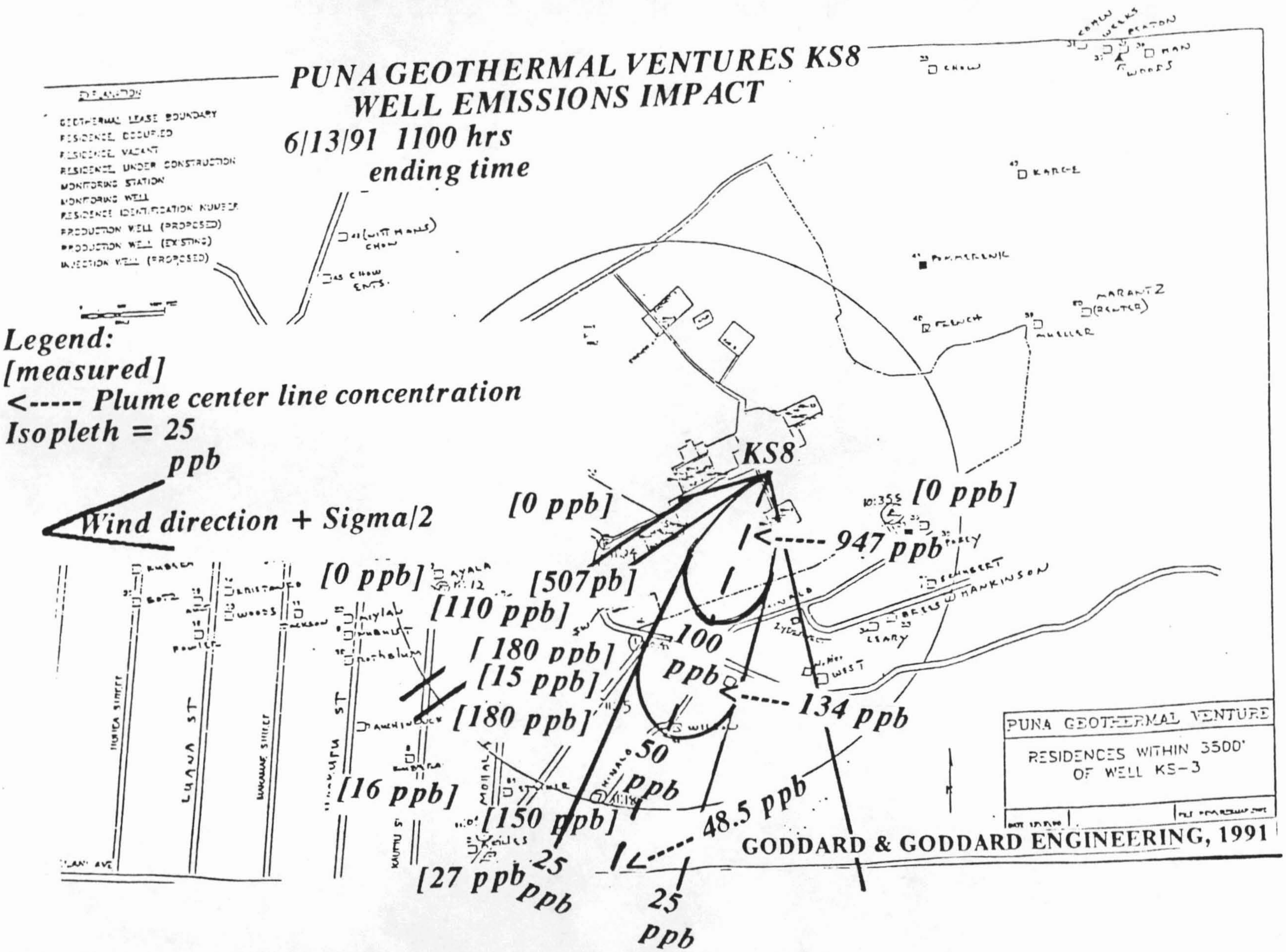

FIGURE 3-8 PGV KS8 WELL VENTING 1000 TO 1100 HOURS
JUNE 13, 1991 LOCAL IMPACT

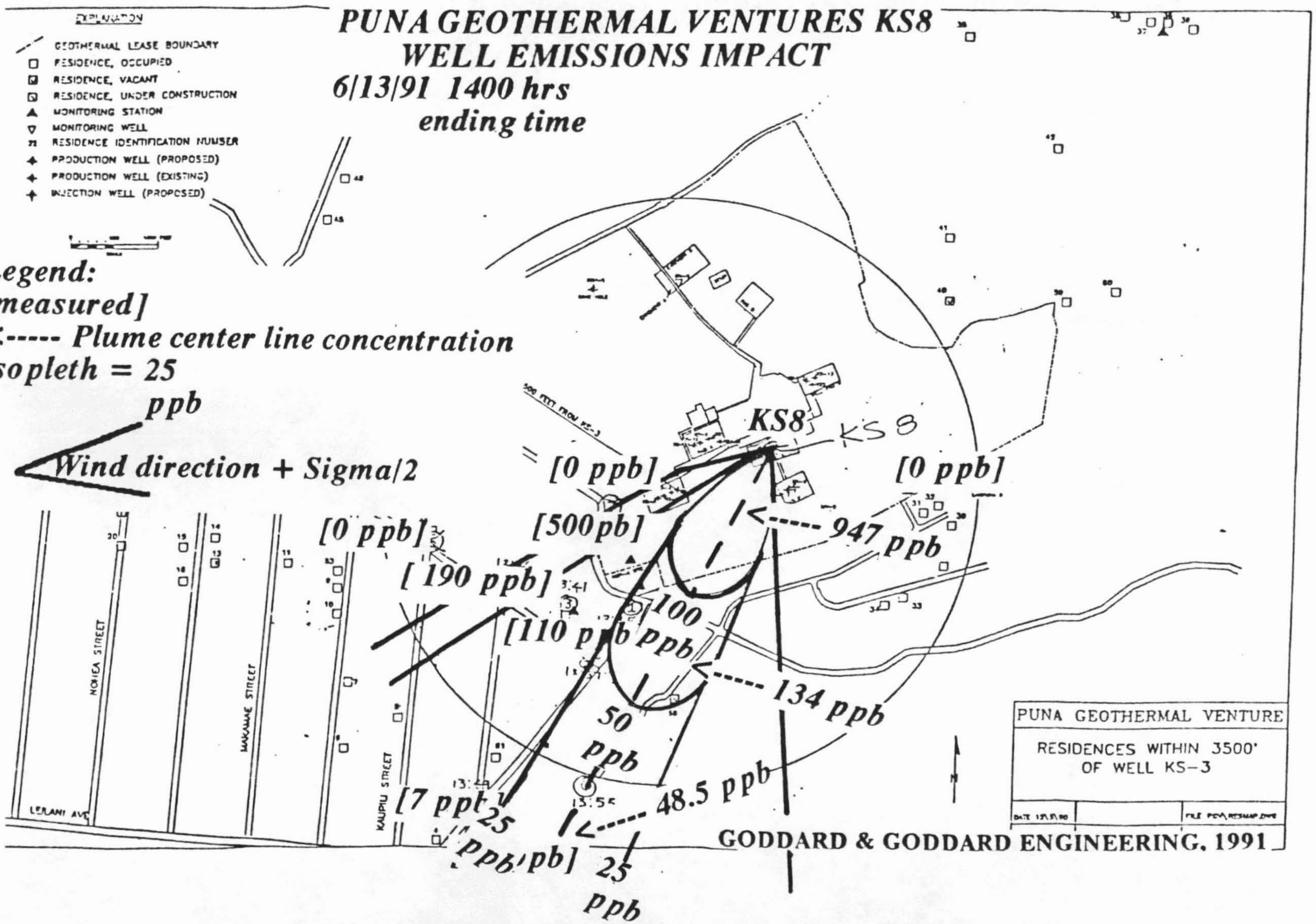

FIGURE 3-9 PGV KS8 WELL VENTING 1300 TO 1400 HOURS
JUNE 13, 1991 LOCAL IMPACT

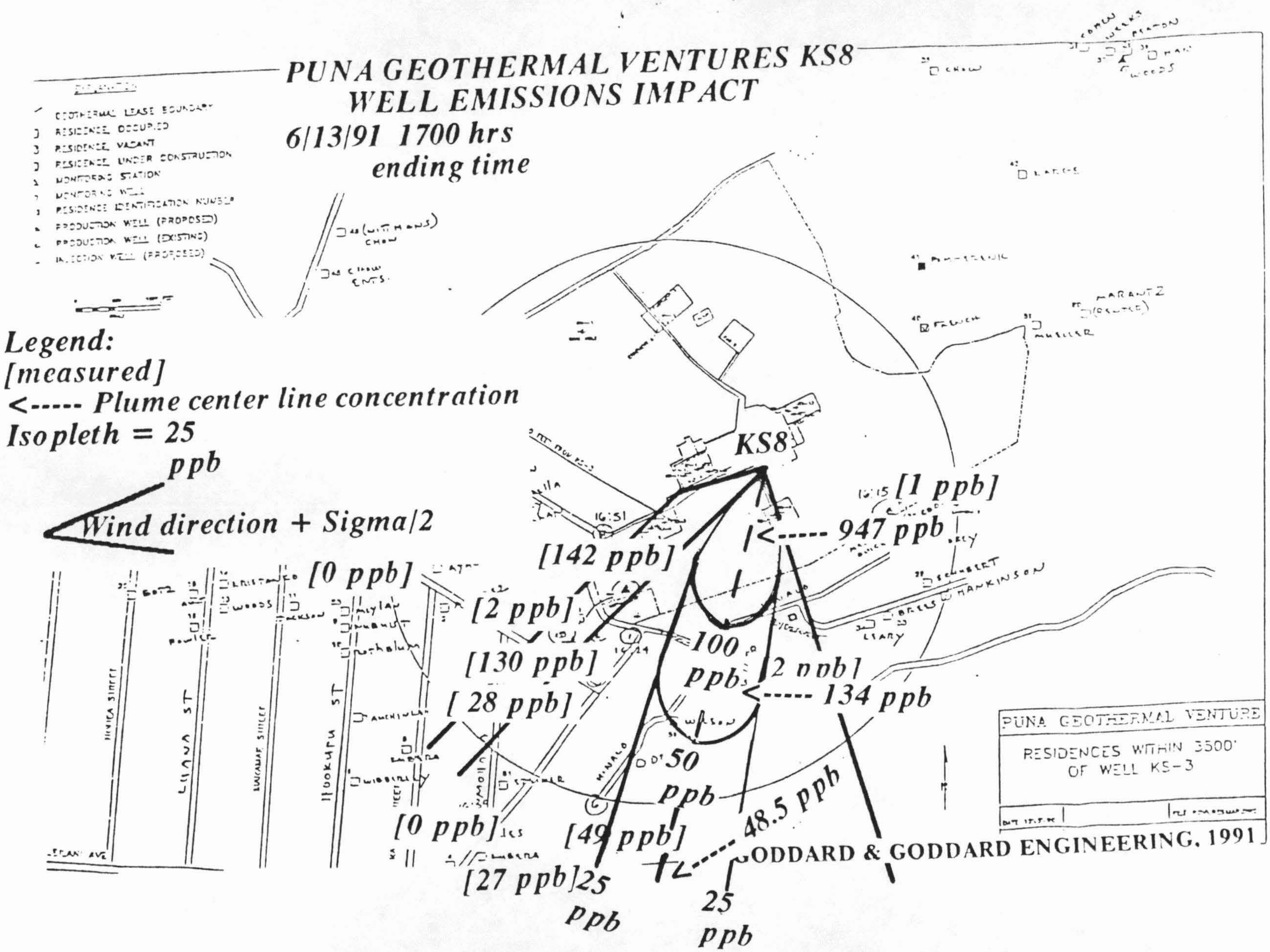

FIGURE 3-10 PGV KS8 WELL VENTING 1600 TO 1700 HOURS
JUNE 13, 1991 LOCAL IMPACT

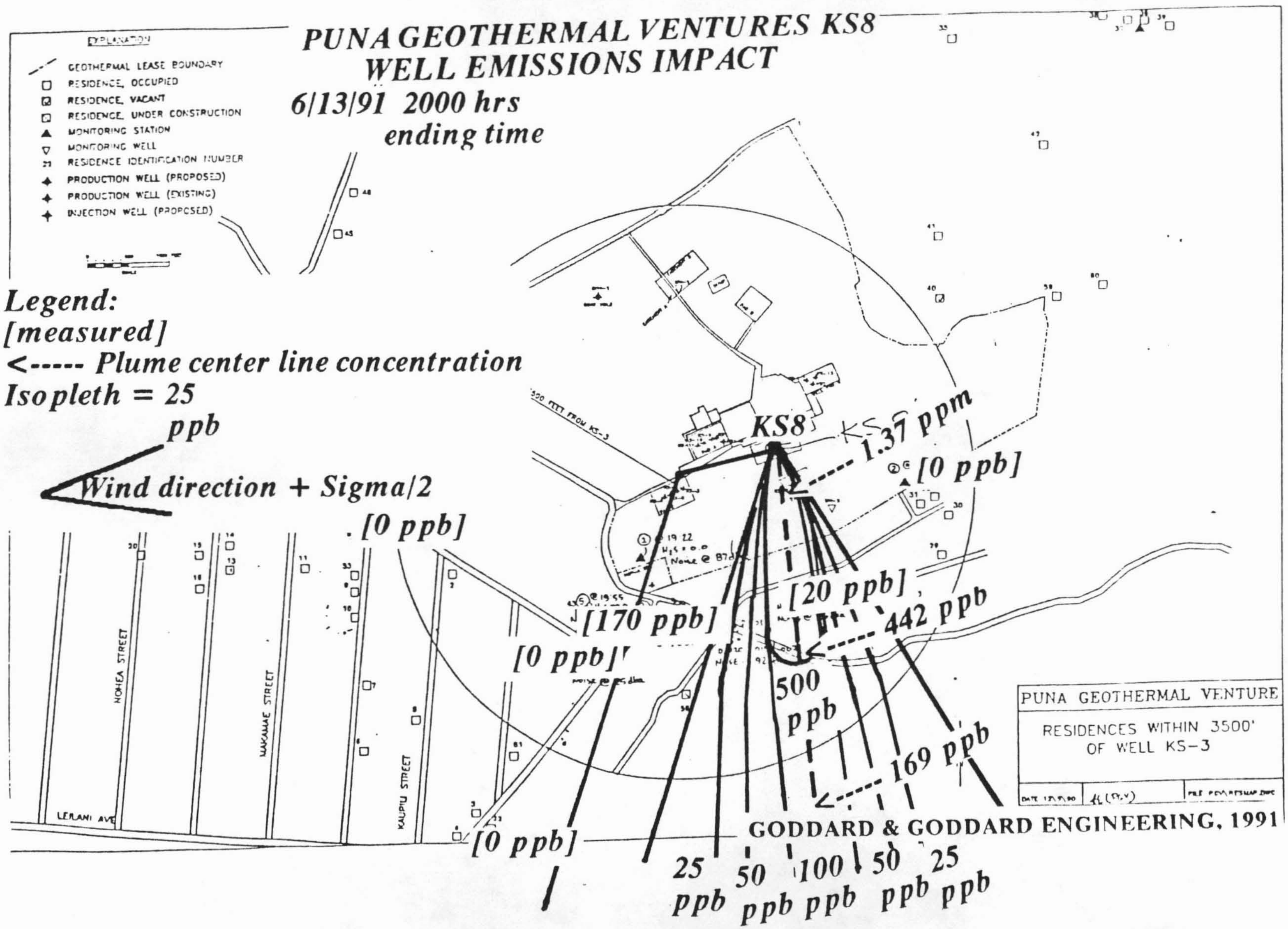

FIGURE 3-11 PGV KS8 WELL VENTING 1900 TO 2000 HOURS
JUNE 13, 1991 LOCAL IMPACT

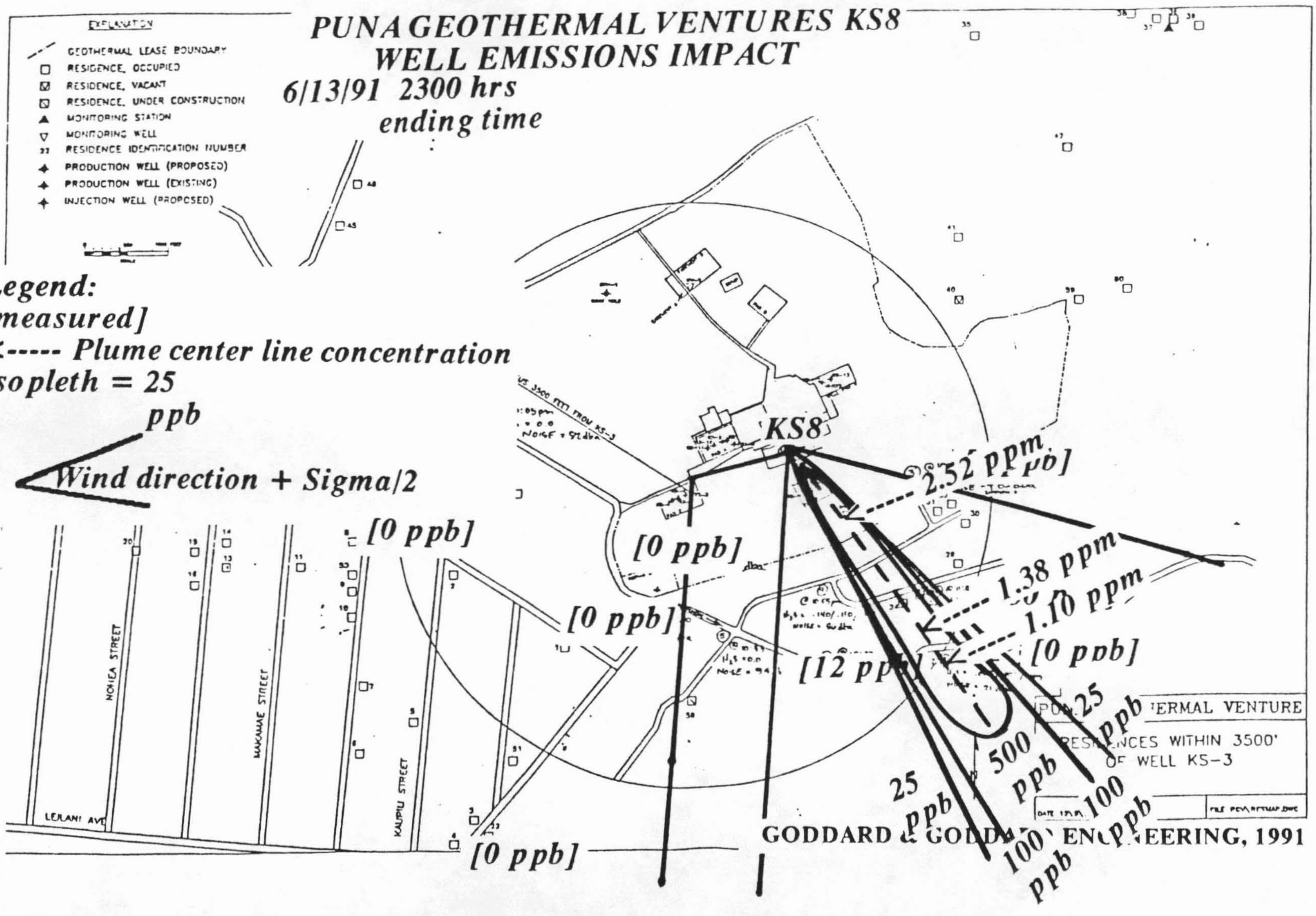

FIGURE 3-12 PGV KS8 WELL VENTING 2200 TO 2300 HOURS
JUNE 13, 1991 LOCAL IMPACT

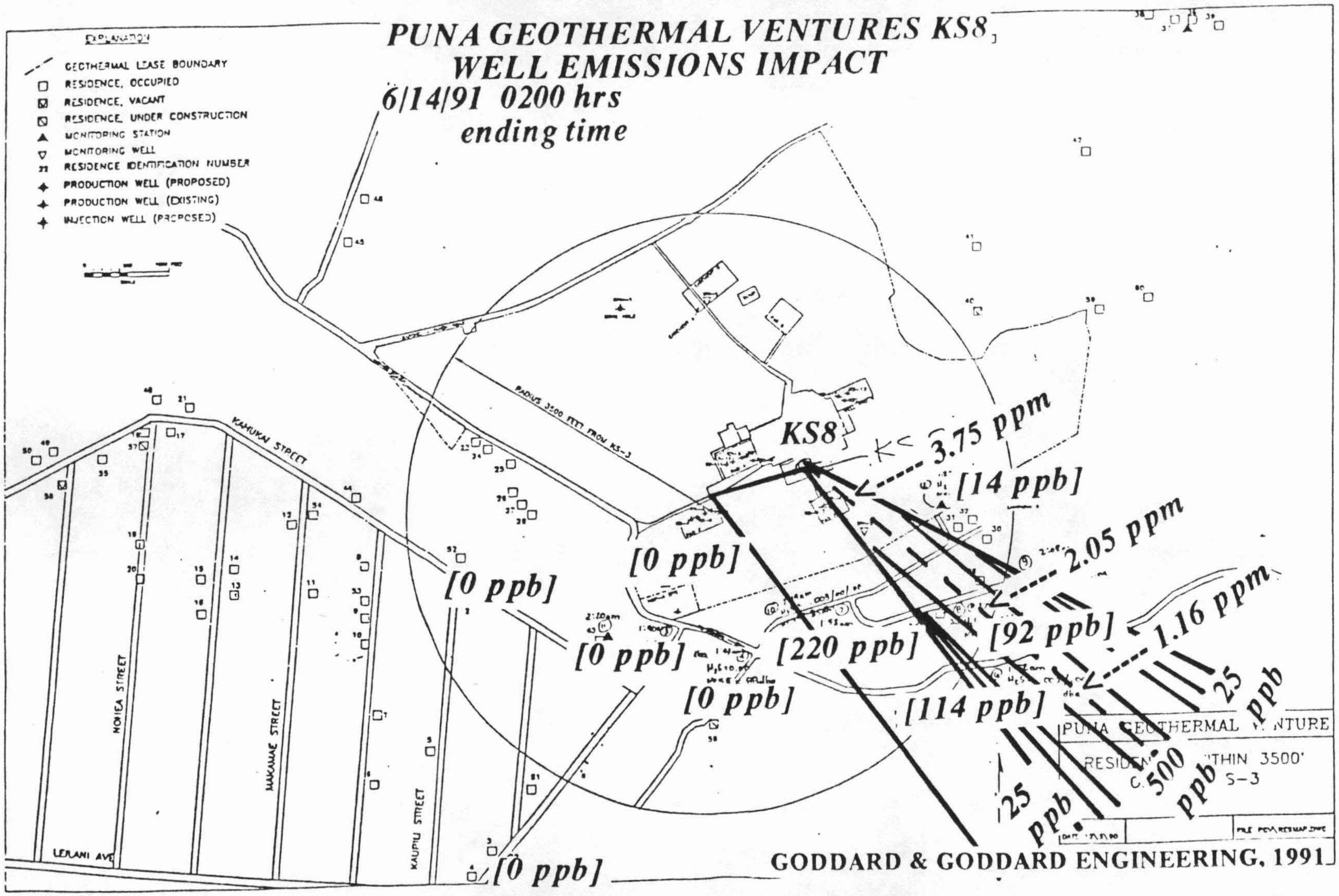

FIGURE 3-13 PGV KS8 WELL VENTING 0100 TO 0230 HOURS
JUNE 14, 1991 LOCAL IMPACT

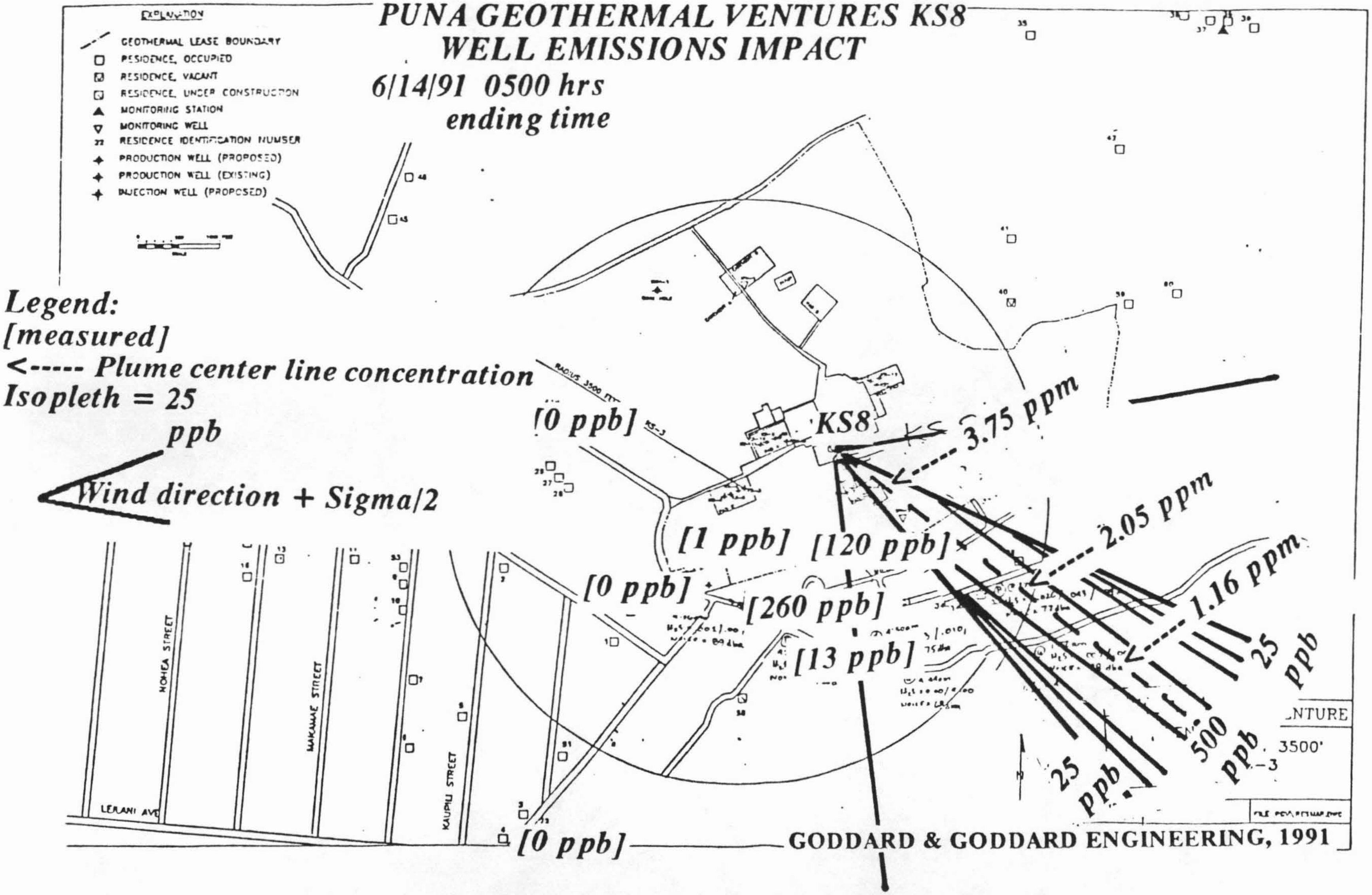

FIGURE 3-14 PGV KS8 WELL VENTING 0400 TO 0530 HOURS
JUNE 14, 1991 LOCAL IMPACT

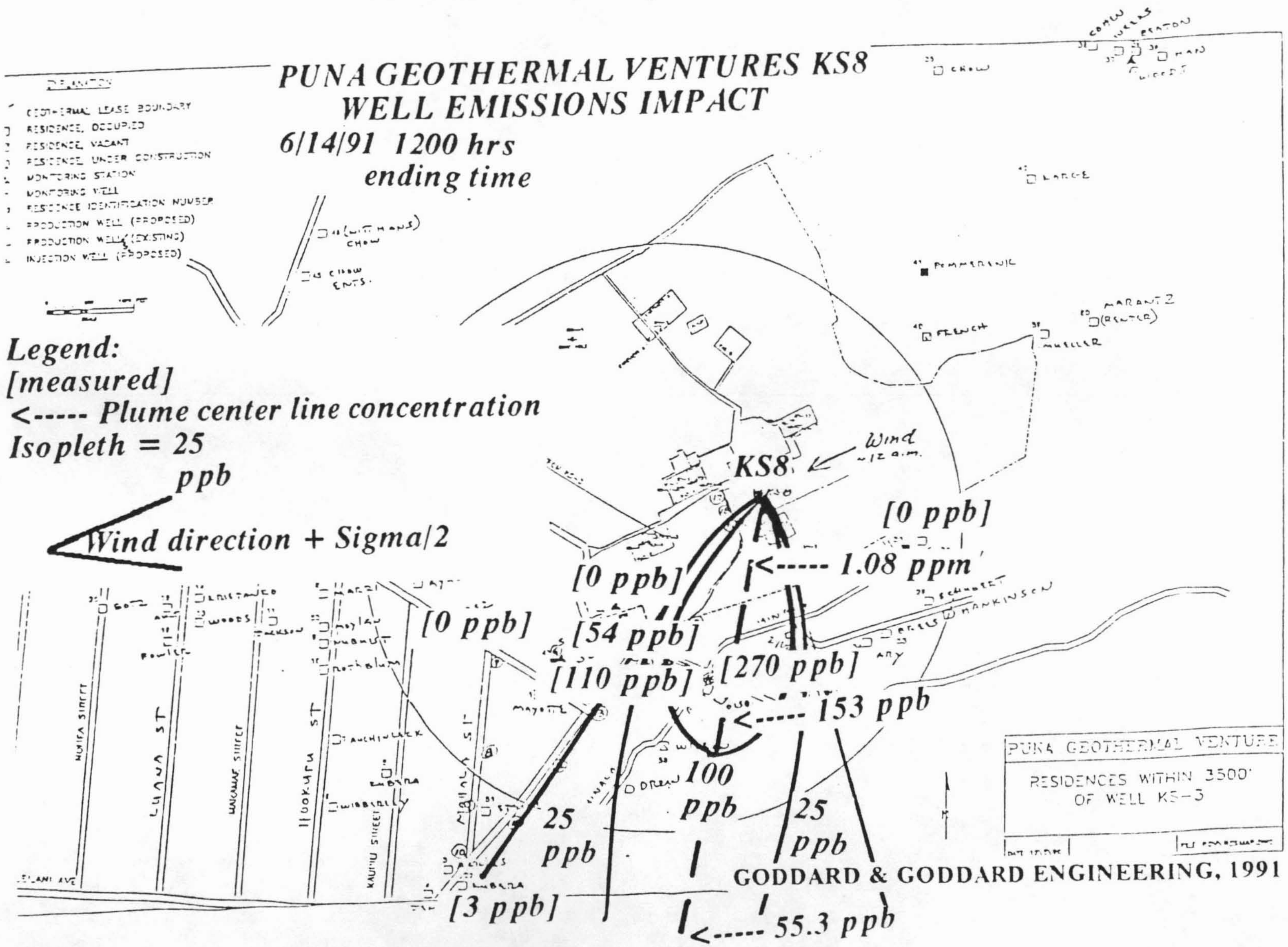

FIGURE 3-15 PGV KS8 WELL VENTING 1000 TO 1200 HOURS
JUNE 14, 1991 LOCAL IMPACT

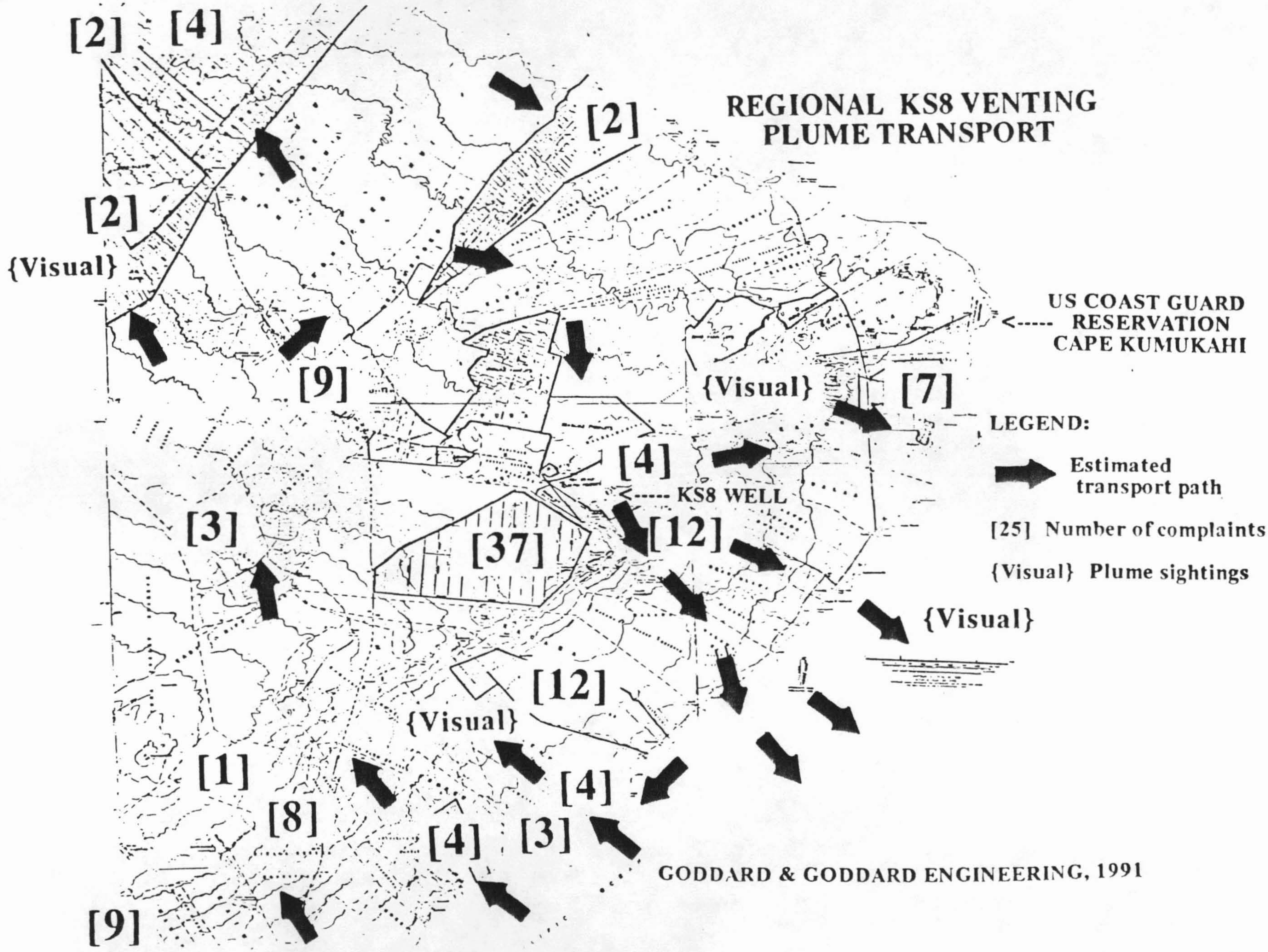

FIGURE 3-16 PGV KS8 WELL VENTING JUNE 12, 13 AND 14, 1991
REGIONAL PLUME TRANSPORT

3.2.1 Local Impact Assessments

The first complete comparison of measured spot readings and station monitoring began at 0100 hrs and is shown in Figure 3-3. From the 2319 hour event to 0200 hrs, no stationary monitoring site indicated an elevated reading. The out-of-plume influence area is clearly shown by the number of bracketed [0 ppb] points. The distance between the parts per million plume centerline and the outer isopleth value of 25 ppb is spanned in a few hundred feet. The values, such as the [280 ppb], [160 ppb] and [63 ppb] values, are all in agreement with the plume estimates. The [63 ppb] value which is outside of the plume positions perimeter is within the plume estimate if the plume centerline is moved to the outer estimated plume position boundary limit. The homes of impacted families are shown in the figures as squares.

The comparison between estimated and measured values of H2S are in substantial agreement for the ending times of 0400 hrs and 0500 hrs. At 0600 hrs, PGV increased venting horizontally at 254 deg. This is shown in Figure 3-6 as the line from the KS8 well site that widens the plume boundary to the west-southwest an estimated 1,200 ft. The effect of the horizontal venting is clearly indicated by the widening width of the area of high measured H2S concentrations.

Wind speed and atmospheric stability change the shape of the estimated plume concentrations. During daytime, as shown in Figure 3-8, dispersion lessens the distance at which high concentrations occur when compared to nighttime conditions such as Figure 3-4. At 1100 hours, as shown in Figure 3-8, the wind direction shifted the plume toward the Leilani Estates. The increased impact to the Estate continued through Figures 3-9, 3-10 and 3-11. At 2300 hours, the winds shifted the plume away from the Estates in a more southeasterly direction as shown in Figure 3-12.

From 0200 hours on June 14, 1991, shown in Figure 3-13, and 0500 hours shown in Figure 3-14, the transport is in a southeasterly direction. At 1200 hours, shown in Figure 3-15, the plume transport again impacts the edge of the Leilani Estate.

3.2.2 Regional Impact Assessment

The saturated steam-and-brine plume was seen at a considerable distance many miles away in part due to the saturated state of the atmosphere which did not evaporate the plume aerosols. In cooperation with the Kapoho Community Association and other concerned groups, health complaint reports were collected and analyzed for their chronological and positional information.

Appendix B contains a breakdown of the communities with health complaint reports, the number of complaints and reported symptoms, and a chronological and positional complaint-related assessment of the plume transport. This information is discussed further in Section 4 where the event impacts are related to referenced health effect symptoms.

The compiled health complaint data, in terms of numbers of complaints, is shown in the regional transport Figure 3-16. Four visual sightings are documented in the complaint files and these position the plume cloud in the areas shown in the figure by the bracketed word {Visual}. The plume was seen 2 miles (3 km) to northeast, 5 miles (8 km) to the southeast by fishermen who avoided penetrating the cloud by staying at sea, 4 miles (6 km) to the southwest when the plume cloud came ashore with the on-shore up-slope morning winds, and 5 miles (8 km) to the northwest where up-slope winds transported the plume cloud into Hawaiian Acres.

The plume transport estimates shown by the arrows on Figure 3-16 are based upon the site meteorological data, the Cape Kumukahi shore meteorological data, and the micrometeorology of local down-slope (katabatic) and up-slope (anabatic) winds analysis. The plume cloud over the two day venting period moved toward the sea during nighttime hours and then was transported inland during the morning hours. Later in the day, the trades again transported the plume seaward. The circular diurnal motion transported the noxious gases, aerosols and particulates over a considerable area as shown in Figure 3-16. The health complaints data chronological and positional data support the transport path estimate shown in Figure 3-16 and as shown in the transport map in Appendix B.

Using the low wind speeds which occurred at 0200 and 0500 hours on June 14, 1991, a capping ground based temperature inversion at 328 ft (100 m) and the 3.88 mph (1.73 mps) measured wind speed, results in the estimated H2S air quality impact, above ambient, listed in Table 3-1.

The ramifications of the health related H2S effects of such exposures as listed in Table 3-1 are discussed in Section 4. The values in Table 3-1 are hourly averages. Three to ten minute peaks would be expected to be 1.6 times higher. For example, at 10 miles the peak level, at a 68% confidence level (mean plus 1 standard deviation) is (58.5 ppb + 23.4 ppb) x 1.6 = 131 ppb (183 ug/m3) H2S concentration above ambient. Impacts for other air toxics listed in Table 1-1, are directly proportional to their respective emissions rates.

TABLE 3-1

KS8 VENTING HIGHEST HOURLY AIR QUALITY IMPACT SUMMARY

General Inversion Dispersion Estimate For Slightly Stable
Pasquil Class E, ground based capping temperature inversion at
328 ft (100m), wind speed 3.88 mph (1.73 mps) which occurred on
June 14, 1991 at 0200 hrs and 0500 hrs.

Receptor Down Wind along transport path		CONCENTRATION ABOVE AMBIENT			
miles	kilometers	ug/m3	±	ppbv	±
1.0	1.6	734.9	256.1	528.7	184.2
2.0	3.2	289.5	100.4	206.8	71.7
3.0	4.8	201.9	80.8	143.7	57.5
4.0	6.5	162.4	65.0	114.4	45.8
5.0	8.1	137.2	54.9	96.6	38.7
6.0	9.7	119.5	47.8	84.8	33.9
7.0	11	106.4	42.6	75.7	30.3
8.0	13	96.2	38.5	68.7	27.5
9.0	15	88.0	35.2	63.1	25.2
10	16	81.2	32.5	58.5	23.4

Note:

Conversion from ug/m3 corrected for temperature and elevation;
The ± uncertainty denotes a 68% probability confidence level;
Values estimated at the plume centerline at 5 ft (1.5 m) height.

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4.0 PUBLIC HEALTH EFFECTS

The environmental health effects of air pollutants are determined by the concentration to which the individual is exposed, individual susceptibility, the mixture of compounds and the duration of exposure.

- **Concentration.** The health effects of various concentrations of air pollutants are summarized in Tables 4-1 and 4-3. A more detailed discussion is given in Goddard (1984).

- **Individual Susceptibility.** Different age groups within the general population are more susceptible than others to the effects of the various emissions. Those with enhanced sensitivity to hydrogen sulfide poisoning include individuals with eye or respiratory tract problems, or anemia, those who have consumed alcohol within 24 hours of exposure, those who have psychiatric problems, infants, and those who have been previously exposed to hydrogen sulfide (IIEQ, 1974). The evidence of "enhanced sensitivity" is not conclusive.

The level and frequency of odor which would annoy individuals varies, and it is frequently not only the concentration level but also the change in concentration which arouses public intolerance (Leonardos et al., 1969). Layton et al. (1981) conclude that an ambient level of 0.03 ppm, hourly average, -- six times higher than the median instantaneous threshold value -- would result in odor nuisance problems, partly because elevated excursions (10 to 15 minutes) during an hour could be particularly annoying.

- **The mixture of pollutants.** The environmental effects of air pollutants listed in Table 4-1 are for individual pollutants. However, they may be synergistic or antagonistic as well as independent (Kestin et al., 1980).

- **The effect of duration of exposure** is related to the other three factors - the concentration, the individual susceptibility and the mixture of pollutants.

The national and state air quality standards are established to reduce or prevent these effects. These standards are based on epidemiological and toxicological studies and assume the existence of threshold levels of concentration below which there are no adverse effects on the general population. The difference between the air quality standard and the threshold level may be defined as a "margin of safety". The larger the margin of safety, the greater the fraction of the population protected by the air quality standard (Case et al., 1977).

Concentrations of hydrogen sulfide below the suggested value of 24 ppb discussed in Section 2 may still constitute a "public nuisance" defined by various Civil Codes:

> "one which affects, at the same time an entire community, or neighborhood or a considerable number of persons, although the extent of the annoyance or damage inflicted on individuals may be unequal".

The health effects of air pollutants often found in geothermal resources and developments are listed in Table 4-1. Occupational Health and Safety Administration (OSHA) health standards are given in Table 4-2 and are designed to protect the working population. The health effects of hydrogen sulfide are listed with references in Table 4-3. The OSHA standards are for a work force and since this excludes the most susceptible portion of the population, these standards when applied to the general population are reduced. The California Department of Health Services (CDHS) interprets Proposition 65 air-borne toxic trigger points concentrations as being 1% to 0.1% of the OSHA TLV values. This is to ensure protection of sensitive individuals which include the young, old and infirm. Recent Air Toxics legislation implementation has been interpreted by CDHS as using the OSHA values divided by 420, as described previously, when applied to the general public (CARB/CDHS 1990).

TABLE 4-1

HEALTH EFFECTS OF AIR POLLUTANTS FROM GEOTHERMAL DEVELOPMENT

Ammonia (NH_3). Odor threshold: 5.2 ppm (Amoore et al., 1983). Eye irritation: 5 ppm (NIOSH, 1974), 72 ppm (Industrial Bio-Test Labs, 1973). Inhalation irritation: 20 ppm (EPA, 1977). Nasal irritation: 32 ppm; chest irritation: 134 ppm (Industrial Bio-Test Labs, 1973). Increased morbidity and mortality: 70-105 ppm (Bittersohl, 1971). Pulmonary edema: 1,700-4,500 mg/m^3. Low levels: no permanent adverse health effects (EPA, 1977). Leaf damage in sensitive plants: 3-12 ppm for 4 hours (Benedict et al., 1955).

Ammonium Bisulfide (NH_4HS). Penetrates the skin more rapidly than hydrogen sulfide. Since it is an inherently unstable solid, it readily dissociates back to hydrogen sulfide and ammonia gases.

Ammonium Sulfate $(NH_4)_2SO_4$. Toxic to plants (Malloch et al., 1979; Sharp, 1976).

Arsenic (As). All forms of arsenic are toxic at various levels; some are potentially carcinogenic (Lee and Fraumeni, 1969; Tseng et al., 1968; Lander, 1975; NIOSH, 1975). Arsenic compounds are known to be corrosive to skin and are identified as a carcinogen. Brief contact has no effect, but prolonged contact can cause skin irritation, with mucous membranes the more sensitive to irritation (CAL/OSHA, 1983). Fluids containing arsenic levels of 5 mg/l (ppm) are considered toxic by the State of California (Department of Health Services, 1984). Odor threshold: 0.50 ppm (Amoore et al., 1983). The fatal dose is 70-180 mg/m^3.

Boron(B). Data related to humans are limited. Several forms of boron are irritants to skin and mucous membranes. Ingestion of 15-20 gm of borax caused acute poisoning. Boron particulate fallout damages plants (Malloch et al., 1979; Sharp, 1976). Exact levels are not given but, for comparison, irrigation water with 10-100 ppm boron content is toxic to plants (Eaton, 1935).

Carbon Dioxide (CO_2). 2% in air can stimulate human respiration. Not considered hazardous when adequate oxygen present (Gennis, 1978). Odor threshold: 74,000 ppm (Amoore et al., 1983).

Chlorides. Not expected to produce adverse health effects (OXY, 1981).

Ethane (CH_3CH_3). A simple asphyxiant. No hazard known in well-ventilated environments (Gennis, 1978). Odor threshold: 120,000 ppm (Amoore et al., 1983).

Hydrogen (H_2). A simple asphyxiant. No hazard known in well-ventilated environments (Gennis, 1978).

Hydrogen Sulfide (H_2S). Odor threshold: 0.0081 (Amoore et al., 1983). Increased neurasthenic effects (fatigue, dizziness, nausea) with long term exposure: above 0.1 ppm. Eye irritation threshold: 10 ppm. Inhalation irritation threshold: 50-100 ppm. Sense of smell stops: 150 ppm. Fatal: 700 ppm. Damage to sensitive plants: more than 0.30 ppm (Thompson, 1976); 40 ppm for five hours (McCallan et al., 1936).

TABLE 4-1 (Continued)

HEALTH EFFECTS OF AIR POLLUTANTS FROM GEOTHERMAL DEVELOPMENT

Mercury (Hg). The human lung absorbs 75-85% at concentrations of 50-350 mg/m^3, almost completely at lower concentrations (Kudsk, 1966). Inhalation produces many adverse effects. Mercury may also be absorbed through the skin or by ingestion. Elimination is slow, resulting in long-term effects which are only partially reversible. Children appear to be especially susceptible (Britt et al., 1976). Methylmercury (CH_3Hg+), the most toxic form, may cause growth deformities (Walton et al., 1978). Inhalation of 100 μg/m^3 can cause chronic mercury poisoning, of 1,200-8,500 μg/m^3 can cause acute poisoning. Occupational exposure to 10-30 μg/m^3 of elemental mercury may cause slight anemia, hypothyroidism and increased excitability. Prolonged exposure may cause neurologic disorders (Walton et al., 1978). Mercury is toxic to plants at levels in the parts per billion range over several days (Jacobson et al., 1970). Over 10 ppm dry weight in plant tissue is toxic.

Methane (CH_4). Odorless. Not known to induce ill effects even at high concentrations in ambient air.

Nitrogen (N_2). No known hazard from its increased presence in ambient air.

Radon-222 (^{222}Rn). Adverse health effects, including lung cancer, may result from inhalation of Radon-222 and its short-lived, alpha-particle emitting daughters (BEIR, 1972). There is at present no known level of exposure to radiation below which no biological damage occurs (Kestin et al., 1980).

Sulfur Dioxide (SO_2). Annual concentrations of 0.05 ppm (130 μg/m^3) led to increased frequency of respiratory illness. The threshold for increased chronic bronchitis in adults and increased acute lower respiratory disease in children is 95-200 μg/m^3 (EPA, 1974; 1975). Hospital admissions with respiratory illness increased when 24 hour sulfur dioxide concentrations were 0.12-0.19 ppm (Finklea, 1973). Odor threshold: 1.1 ppm (Amoore et al., 1983). Irritation threshold: more than 3 ppm (Case et al., 1977). 1-10 ppm (2,600-26,000 μg/m^3) increased airway resistance in humans and other animals. More than 400 ppm caused death. 0.3 ppm for 8 hours is toxic to plants (Gauch et al., 1954).

Sulfates. Taste/odor threshold: 700 μg/m^3. Irritation Threshold: 350-2,000 μg/m^3. 10-3,000 μg/m^3 can cause illness (Case et al., 1977; Layton et al., 1981). Brief exposure to 700-5,000 μg/m^3 sulfuric acid mist (H_2SO_4) resulted in increased airway resistance.

Suspended Particulate Matter. The health effects of suspended particulate matter depend on the particle size and chemical composition. "No effects" threshold: 100 μg/m^3 (Case et al., 1977). Morbidity threshold: 300-375 μg/m^3 (DHEW, 1970). Mortality threshold: 200-750 μg/m^3. Particles larger than 0.5-2 μm diameter are usually trapped in the upper respiratory system and cleared in a few minutes. Smaller particles may remain in the body for months or years (Case et al., 1977).

TABLE 4-2
OSHA OCCUPATIONAL STANDARDS FOR AIRBORNE CONTAMINANTS

SUBSTANCE	PEL (1) ppm	mg/m3	EXCURSION LIMIT (2)	EXCURSION DURATION (3) ppm	CEILING LIMIT (4)	MAXIMUM CONCENTRATION (5)
AMMONIA	25	18				37.5 ppm
ARSENIC and inorganic arsenic compounds	-	0.01				.03 mg/m3
ARSENIC, organic compounds, as As	-	0.2				0.6 mg/m3
ARSINE	0.05	0.2				0.15 ppm
BENZENE	10	30	25	8 hrs/ 10 min	50 ppm	
BORON OXIDE	-	10				20 mg/m3
BORATES Anhydrous and pentahydrate	-	1				3 mg/m3
decahydrate	-	5				10 mg/m3
CARBON DIOXIDE	5,000	9,000				7,500 ppm
ETHANE (limiting factor is available oxygen)						
HYDROGEN SULFIDE	10	15	20	8 hrs/ 10 min	50 ppm	
MERCURY alkyls as Hg	0.001	0.01			0.04 mg/m3	
all forms except alkyls as Hg vapor	-	0.05			0.1 mg/m3	
aryl and inorganic compounds	-	0.1			0.2 mg/m3	
DUST	10 (5 Respirable)					
SULPHUR DIOXIDE	5	13				10 ppm

RADON-222(1) 3,000 pCi/m^3 (3.0 pCi/l) uncontrolled areas
100,000 pCi/m^3 (100 pCi/l) controlled areas

SOURCE: Summarized from OSHA Publication 5155

EXPLANATION OF TABLE 4-2

(1) PEL (Permissible Exposure Limit) - the maximum permitted 8-hour time weighted average concentration of an airborne contaminant. The PEL reflects the conditions and amounts of a substance to which most workers can have a daily exposure during a 40 hour work week for a working lifetime without suffering ill effects. The PEL may be established to protect against illness, disease, irritation, narcosis, nuisance or other forms of stress. PELs apply only to occupational settings and occupational exposures.

(2) Excursion Limit - the maximum concentration of an airborne contaminant to which an employee may be exposed without regard to duration provided the 8-hour time weighted average concentration does not exceed the permissible exposure limit.

(3) Excursion Duration - the maximum time period permitted for an exposure above the excursion limit but not exceeding the ceiling limit.

(4) Ceiling Limit - The maximum concentration of an airborne contaminant to which an employee may be exposed at any time.

(5) Maximum Concentration - where the ceiling limit is not specified, the maximum concentration to prevent adverse health effects is calculated as in 5155 (c) (2) (B).

(6) In the absence of information to the contrary, the adverse health effects of exposure to two or more toxic materials during the workday shall be considered additive.

TABLE 4-3

HEALTH EFFECTS OF HYDROGEN SULFIDE ON HUMANS

Concentration ppm	mg/m^3	Effects	Reference
0.020 to 0.039	0.028 to 0.055	Harmful long term effects on adults and the growth of young organisms especially infants.	Glebova c.b. Loginova (1957)
0.070	0.098	Affects light sensitivity of the eye.	Tuan c.b. Meyer (1978)
0.086	0.12	Increased incidence of mental depression, dizziness and blurred vision.	Schieler c.b. IIEQ (1974)
0.32	0.45	Increased incidence of nausea, loss of sleep shortness of breath and headaches following chronic exposure.	U.S. Public Health (1964) c.b. IIEQ (1974)
0.71 to 7.1	1.0 to 10	Increased incidence of decreased corneal reflex (convergence and divergence) after chronic exposure.	Rubin and Arieff (1945), Lewey (1938) c.b. IIEQ (1974)
7.1 to 50	10 to 70	Irritation of conjunctiva, fatigue, loss of appetite and insomnia after chronic exposure.	Barthelmy (1938) Masure (1950), Ahlborg (1952), c.b. IIEQ (1974)
10 to 15	14 to 21	Conjunctival and corneal inflammation, "threshold of irritation" according to Gurinov.	Butrin, Arkhangels' kii c.b. Gurinov (1952)
50 to 107	70 to 150	Irritation to eyes, i.e., conjunctivitis and keratitis with photophobia, after several hours of exposure.	Deveze (1957), Beasley (1963), Nyman (1954), c.b. IIEQ (1974)
50 to 100	70 to 140	Sub-acute poisoning, mild conjunctivitis and mild respiratory tract irritation after one hour exposure.	Yant (1930) c.b. Moyer (1978)
100	140	Slight symptoms may appear after several hours.	Fairhall (1957) c.b. Moyer (1978)

TABLE 4-3 (Continued)

HEALTH EFFECTS OF HYDROGEN SULFIDE ON HUMANS

Concentration ppm	mg/m^3	Effects	Reference
100	140	Paralyzes the olfactory nerve.	Poda (1966)
70 to 150	98 to 210	Slight symptoms after several hours exposure.	Henderson & Haggard (1943) c.b. Moyer
107 to 210	150 TO 300	Slight systemic symptoms after many hours of exposure; possible hemorrhage and death within 48 hours.	Henderson & Haggard (1943), Haggard (1925), c.b. IIEQ (1974)
150	210	Olfactory paralysis almost immediately.	Evans (1967) c.b. DWR (1978)
160	225	Olfactory paralysis.	IIEQ (1974)
160	225	Irritation to respiratory tract and eyes within 1 hour, becoming more severe with longer exposure, i.e., conjunctivitis, bronchitis and keratitis with photophobia.	Nyman (1954), Ahlborg (1952), Mitchell and Yant (1925), Carson (1963) c.b. IIEQ (1974), DWR (19
170 to 300	238 to 420	Maximum concentration that can be inhaled for one hour without serious consequences.	Henderson & Haggard (1943) c.b. Moyer (1978)
200 to 300	280 to 420	Sub-acute poisoning, marked conjunctivitis and respiratory tract irritation after one hour exposure.	Yant(1930) c.b. Moyer (1978)
210 to 360	300 to 500	Nervous system depression.	Ahlborg (1952) c.b. IIEQ (1974)
210 to 360	300 to 500	Slight systemic symptoms within 4 to 8 hours, hemorrhage and death within 48 hours.	Henderson & Haggard (1943), Haggard (1925), Mitchell & Yant (1925) c.b., IIEQ (1974)

TABLE 4-3 (Continued)

HEALTH EFFECTS OF HYDROGEN SULFIDE ON HUMANS

Concentration ppm	mg/m^3	Effects	Reference
210 to 360	300 to 500	Irritation to respiratory tract, eyes and loss of smell within 30 minutes becoming more severe with longer exposure; photophobia and dypsnea (difficult breathing) within 4 hours, possible pulmonary edema.	Haggard (1925), Breysse (1961), Mitchell & Yant (1925), c.b. IIEQ (1974)
360 to 500	500 to 700	Slight systemic symptoms within 4 hours, hemorrhage and death within 8 hours.	Henderson & Haggard (1943), Mitchell & Yant (1925) c.b. IIEQ (1974)
360 to 500	500 to 700	Irritation to respiratory tract and eyes and loss of sense of smell within 30 minutes; dypsnea, conjunctivitis and keratitis with photophobia within 1 hour. Possible pulmonary edema.	Haggard (1925), Breysse (1961), Mitchell & Yant (1925) c.b., IIEQ (1974)
400 to 700	560 to 1,000	Dangerous exposure after 30 to 60 minutes exposure.	Henderson & Haggard (1943) c.b., Moyer (1978)
600	840	Fatal after 30 minutes.	Henderson & Haggard (1943) c.b. Moyer (1978)
500 to 640	700 to 900	Slight systemic symptoms within 1 hour, i.e. headache, dizziness; unconsciousness and death within 4 to 8 hours.	Henderson & Haggard (1943), Mitchell & Yant (1925) c.b. IIEQ (1974)
500 to 640	700 to 900	Serious irritation to respiratory tract and eyes within 30 minutes, i.e., coughing, bronchitis, pharyngitis, dypsnea, possible pulmonary edema, photophobia, conjunctivitis and keratitis.	Haggard (1925), Breysse (1961), Mitchell & Yant (1925), IIEQ (1974)
500 to 700	700 to 1,000	Sub-acute poisoning, dangerous in 30 minutes to 1 hour.	Yant (1930) c.b. Moyer (1978)

TABLE 4-3 (Continued)

HEALTH EFFECTS OF HYDROGEN SULFIDE ON HUMANS

Concentration ppm	mg/m^3	Effects	Reference
640 to 1,000	900 to 1,400	Systemic effects predominate over local irritation effects. Systemic symptoms within 30 minutes, collapse, asphyxia and death within 1 hour.	Henderson & Haggard (1943), Mitchell & Yant (1925), Simpson & Simpson (1971) c.b. IIEQ (1974)
710 to 1,500	1,000 to 2,100	Lethal to man.	Gurinov (1952)
700 to 1,000	1,000 to 1,400	Possible acute poisoning, rapid unconsciousness, death.	Yant (1930) c.b. Moyer (1978)
700 to 900	1,000 to 1,300	Rapidly produces unconsciousness, cessation of respiration and death.	Poda (1966)
1,000	1,400	Rapidly fatal.	Fairhall (1957) c.b., Moyer (1978)
1,000 to 2,000	1,400 to 2,800	Acute poisoning, rapid unconsciousness, death in a few minutes.	Yant (1930) c.b. Moyer (1978)
1,000 to 2,000	1,400 to 2,800	Systemic effects predominate over local irritant effects. Immediate systemic symptoms, i.e., stimulation of respiratory (hypernea), followed by respiration inactivity (apnea) collapse, asphyxia and death within 30 minutes.	Patty (1963) c.b. Haggard (1925) Haggard & Henderson (1922) c.b. IIEQ (1974)
2,000 to above	2,800 to above	Systemic effects predominate over local irritant effects. Paralysis of respiratory center; immediate death.	Haggard (1925) Yant (1930) c.b. IIEQ (1974)

4.1 COMMUNITY HEALTH IMPACT ASSESSMENT

Health complaints have been and are in the process of being collected by several individuals, concerned citizen groups and by State and County Agencies. A compilation of presently available health complaints has been provided through the work of Mrs. Hedtke, Secretary of the Kapoho Community Association and through cooperation with the Big Island Rain Forest Action Group, Colleen Mandals, and many others. A summary of the results shown by area impacted in Figure 3-16 is listed in Table 4-4 which includes the tabulation of 123 health complaints.

The compilation is included in Appendix B and lists 26 symptoms tabulated for 17 communities surrounding the PGV site. The odor of sulfur, eye irritations, and trouble breathing were experienced by every community included in the survey. Of the 123 respondents, 8 required medical care, 87 (70%) heard the venting noise of which 85 found the noise irritating (69%), 97 smelled sulfur (79%), 74 (60%) experienced eye irritation, 77 (63%) experienced throat irritation, 18 (15%) experienced trouble breathing, 24 (20%) experienced coughing and wheezing, and 24 (20%) experienced nose irritation.

The referenced start of eye effects in Table 4-3 occurs at a level of 70 ppb H2S, with dizziness and depression at 86 ppb, followed by nausea and loss of sleep at 320 ppb. The onset of conjunctival and corneal inflammation, which is the basis of the OSHA 8 hour worker standard occurs at a referenced 10 ppm (10,000 ppb).

Exposed individuals and families within a one mile radius of the KS8 well venting were estimated to have been impacted at H2S levels indicated in Figures 3-3 through Figures 3-15. Concentrations of H2S in the first mile (1.6 km) from the venting site are estimated to have exceeded 500 ppb with centerline peaks above 2,000 ppb (2 ppm). The initial steam and brine cloud is estimated to have concentrations of 900 ppm. Emissions that were restricted by the drill rig decking or were expansion cooled, are estimated to have produced periods where peaks could have exceed 36 ppm at 528 ft (160 m) and 1.36 ppm at 1.0 mile (1.6 km).

Individuals down wind are estimated to have been exposed to concentrations, above ambient, as listed in Table 3-1. Peak values, 3 to 10 minute average, at a 68% confidence level are estimated at as far as 10 miles (16 km) to exceed 131 ppb with an hourly average concentration of 81.9 ppb at the plume centerline.

The health complaint symptoms that are compiled in Table 4-4 are referenced at levels starting at 20 ppb in Table 4-3. Severe eye inflammation at 10 ppm are estimated to occur for those individuals or families that were exposed to the plume within 1,000 ft (348 m) of the KS8 well venting site.

A previous health study conducted in 1987 of residents in the Puna area, found that chronic respiratory conditions including bronchitis/emphysema, asthma, hayfever, sinusitis and other respiratory system diseases rates were higher than reported in Hawaii County or statewide in 1983 (Anderson, 1987). Individuals with such respiratory illnesses are more sensitive to adverse health effects of gaseous and particulate pollutants.

Other toxic constituents of the steam and brine cloud are listed in Table 1-1. The Total Dissolved Solids estimated emissions listed in Table 1-1 are estimated to result in high concentration impacts of aerosols and particulates in the steam and brine cloud. For instance the 13.6 lb/hr of lead results in an estimated hourly average exposure at 10 miles along the plume centerline of 8.59 ug/m3 above ambient. While the exposure time was short for individuals and no long term adverse health effects are foreseen, the high levels of gaseous air toxics concentrations added to other heavy metals, aerosol, particulates and H2S are estimated to have given rise to the reported adverse health complaints.

TABLE 4-4

KS8 WELL VENTING COMMUNITY HEALTH COMPLAINTS

Name	Distance miles	Direction	Health Complaint Numbers
Puu Honuaula	0.6	East	4
Lanipuna	3	South	12
Pohoiki Bay Estates, Leilani	1	Southwest	37
Opihikao Homesteads	1	Southwest	12
Puna Palisades	5	South	3
Kehena	4	South	4
Kalapana Seaview Estates	10	Southwest	9
Black Sands Subdivision	6	Southwest	8
Upper Kaimu Homesteads	7	Southwest	1
Kamaili Homesteads	4	South	4
Kaohe	5	South	3
Ainaloa, Orchidland	9	Northwest	2
Hawaii Acres	8	Northwest	2
Hawaiian Paradise Park	9	Northwest	4
Hawaiian Beaches, Hawaiian Shores	5	Northwest	2
Pahoa, Nanawale	4	Northwest	9
Kapoho	4	Northeast	7
	Total Health Complaints		123

Source:
Appendix B
Big Island Rain Forest Action Group
Colleen Mandals, Pahoa Natural Foods
Kapoho Community Association

5.0 SUMMARY AND CONCLUSIONS

The following findings are in accord with those in the Element III Part I report. The focus here is on the air quality and adverse health effects of the event.

The air quality impacts of the KS8 June 12, 13 and 14, 1991 blow-out resulted in high emission levels of H2S and other air toxics from the project area. Individuals and families near and surrounding the site for several miles experienced periods where health complaints resulted from exposures to the released air toxics in the form of gases, aerosols and particulates.

Local values of H2S, measured and estimated, have been shown to be in substantial agreement within 1.0 mile (1.6 km) of the release site. The zone of high impact was increased by PGV horizontal venting.

Regional estimated plume transport to 10 miles has been shown to compare to regional coastal wind measurements, to land and sea based local wind generation, to local plume cloud sightings, and to the observed chronology and position of health complaints. Estimates of 10 mile impacts of H2S within the plume cloud centerline are high enough to yield observed symptoms at concentrations as referenced in the report.

A "worst case" impact event with the same emissions as the KS8 uncontrolled venting where winds were near calm or at 1.0 mph (0.4 mps) would have increased impacts an estimated 4 to 10 times. Under worst case conditions, the distance to where health complaints were reported would be extended several fold.

It appears that the event was due to lack of preparedness and mismanagement of techniques which could have prevented unabated H2S releases. It is our opinion that the permittee has apparently violated air H2S emissions limits and H2S air quality impact limits, as well as other ambient air quality standards for other air toxics, as well as noise level limits and noise level control average criteria permit requirements.

It appears the permittee has failed to use and/or manage the use of Best Available Control Technology in abating the air emissions and the noise levels. It appears the permittee has used equipment not described in the Authority to Construct which may have added to the air emissions and noise levels during the event.

The DOH air quality and noise permit conditions were stringent enough, if they had been followed by PGV, to protect the health and safety of the surrounding citizens. Unfortunately, only a few foresaw the likelihood of such a high concentration of air toxics emissions and such a prolonged venting period.

6.0 RECOMMENDATIONS

The following recommendations are in accord with those in the Element III Part I report. The focus here is on avoiding future emission exceeds and in documenting, in the surrounding communities, possible future air quality impacts and adverse health effects. It is recommended that PGV pay for any additional expense involved in implementing the following measures:

1. Emissions limits for H2S be vigorously and rigidly enforced by DOH personnel.

   o. Implement emissions limits with frequent field inspections by DOH personnel on an unannounced basis to verify compliance.

   o. Emission rate measuring procedures, equipment and a maintained database should be implemented which quantify the emission rates and log the emissions data.

   o. Geochemical analysis of the resources should be verified frequently by independent laboratory analysis.

   o. New resources should be immediately geochemically analyzed at a frequency at which minimal changes between samples is observed.

   o. Developed resources should be geochemically analyzed on a quarterly basis with more frequent analyses if a 10% change is observed between analyses.

2. A Puna Air Monitoring Program (PAMP) be formed managed by DOH with participation by the developer, the local agencies, State agencies, local concerned organizations and local concerned citizens.

   o The PAMP committee should be responsible for managing an independent agency or contractor management of the air and noise monitoring program.

   o Costs of the program should be borne by the developer.

   o Monitoring sites should be unified under the PAMP program.

   o Sites should establish a uniform Quality Assurance program to standards established by the USEPA.

   o The committee should be responsible for Quality Assurance of all data with reports unified under the PAMP program.

   o The committee should establish routine third party station audits which should be performed by qualified personnel.

- o Equipment operated in the PAMP program should be as uniform as possible with uniform data logger formats, and report structures, and should have data modem-accessible for Operational Management of Air Resources (OMAR) type functions (see Appendix C).

- o The committee should coordinate the availability of data through a central computer system linked by telephone and/or telemetry so the emergency response will be automatic 24 hours a day for each station.

- o The committee should coordinate with a limited number of external users to the data archiving central OMAR type computer so that non quality assured data is made available to the public.

- o The committee should oversee the recommended equipment installation and, before further geothermal exploration occurs in the area, conduct meteorological investigations of the proposed new explorations area to clearly establish the "worst case" micrometeorological relationship between the area's future geothermal emissions and local and regional impacts.

3. Modify station positions and install additional meteorological monitoring equipment and sites to further study the geothermal air pollution meteorology of the location and zone of impact as shown in Figure 6-1. Each of the station changes should be done sequentially starting with the present stations farthest from the PGV site.

   A. PGV Site specific measurement stations - these stations and locations are designed to define the micrometeorology, the conditions aloft, and possibly record and give alarm on elevated H2S emission events near PGV planned and upset venting sites.

      - o To better define the atmospheric stability and winds near the surface and aloft near the PGV site, it is recommended that a 40 meter tower be installed at a convenient location near the present Irvine station. The tower should be equipped with wind speed, wind direction, temperature and humidity at 40 meters, 20 meters and at 10 meters so that atmospheric stability, and the magnitude and gradient of temperature, wind speed and humidity may be obtained. The tower should be equipped with a data logger and linked through telephone or telemetry to the central OMAR type computer.

      - o Discontinue meteorological monitoring at the SW station, since the station is close to the Irvine station, while maintaining the air quality monitoring. Equip the station with the ability to measure H2S in the lower ppb range and with a second instrument or autoranging measure H2S in the mid to high ppm range. Link the station into the central OMAR type computer system by telemetry or telephone.

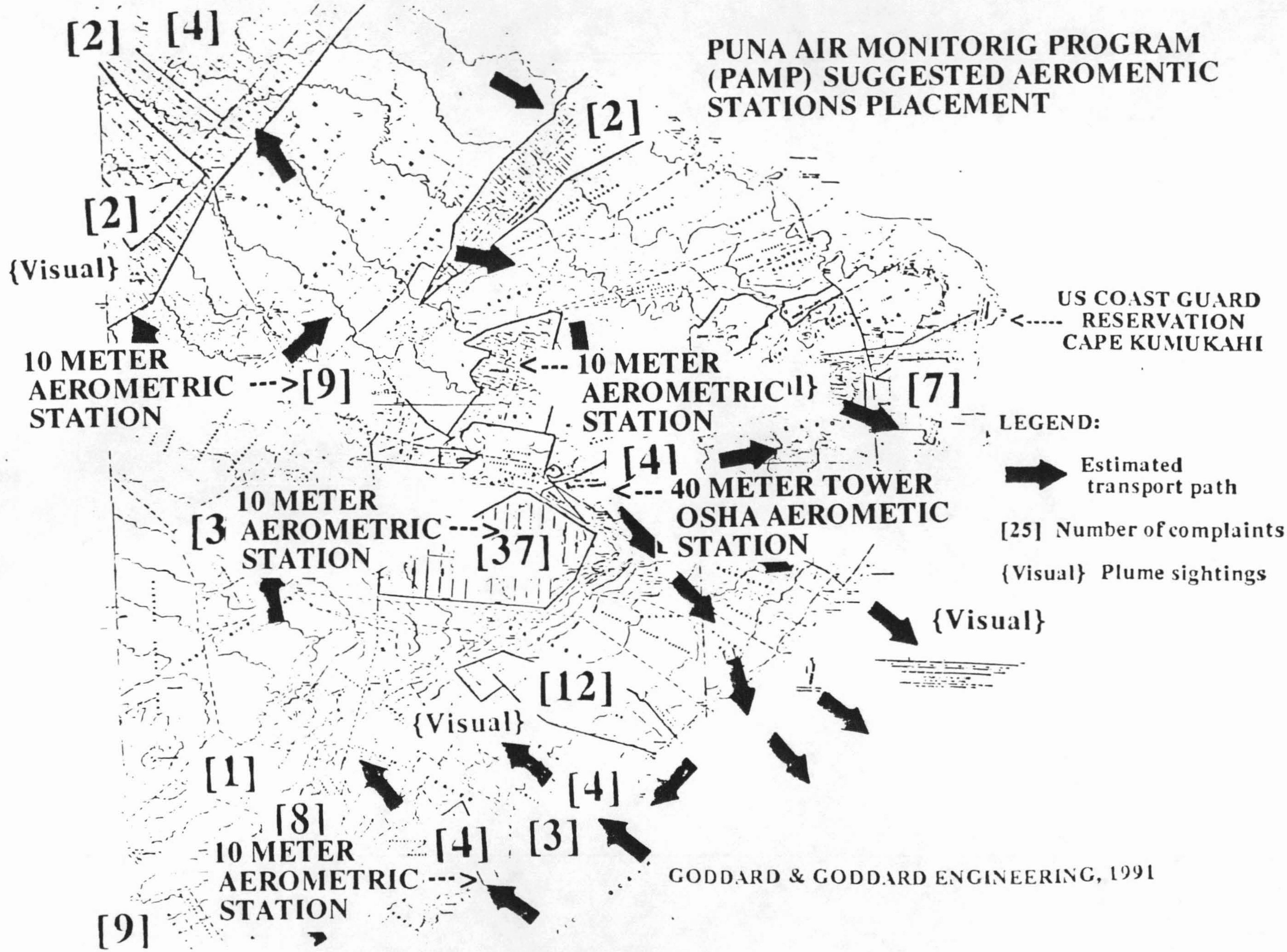

FIGURE 6-1 SUGGESTED PAMP AEROMETIC MONITORING STATIONS PLACEMENT

B. Surrounding Community Aerometric Stations - these stations and locations are designed to gain a more regional understanding of the micrometeorological conditions and provide air quality surveillance and emergency community warning.

- o Relocate the Wade station within the interior of the Leilani Estates. Equip the station with H2S monitoring in the ppb range, and 10 meter wind speed, wind direction including sigma, temperature, humidity and precipitation. Link the station into the central OMAR type computer system by telemetry or telephone.

- o Relocate the Wood site within the Pahoa community. Equip the station with H2S monitoring in the ppb range, and 10 meter wind speed, wind direction including sigma, temperature, humidity and precipitation. Link the station into the central OMAR type computer system by telemetry or telephone.

- o Relocate the Alvarez station within the Kaniahiku community. Equip the station with H2S monitoring in the ppb range, and 10 meter wind speed, wind direction including sigma, temperature, humidity and precipitation. Link the station into the central OMAR type computer system by telemetry or telephone.

- o Relocate the SE station within the Kehena Beach Subdivision so that coastal conditions are more adequately monitored. Equip the station with H2S monitoring in the ppb range, and 10 meter wind speed, wind direction including sigma, temperature, humidity and precipitation. Link the station into the central OMAR type computer system by telemetry or telephone.

- o A uniform method of sampling precipitation at each PAMP station should be initiated with regular chemical assessments of the constituents including heavy metals until the background conditions are well understood;

- o The PAMP committee should oversee development of a uniform monitoring program of known PGV geothermal air toxics which through "worst case" dispersion analysis estimation surpass a health significance level of 1:100,000 in any populated area.

4. PAMP manage local and regional air transport studies in future geothermal explorations areas before initiation of geothermal development.

   - A series of "worst case" poor air dispersion meteorological condition tracer studies should be initiated in new areas of geothermal explorations. If the new area is a step-out from the PGV location, the study should include releases at the PGV power plant site rock muffler, simulating estimated steam plume rise, and at possible normal operations and upset conditions venting points in the well field. Multiple tracer sampling sites should be situated in communities which may be impacted in addition to mobile and aircraft grab sampling. The temperature and wind structure aloft should be monitored during the tests.

   - Each tracer study should be paid for by the developer with adequate funds for the PAMP committee to hire a qualified firm to conduct the tests. The firm should statistically assess the frequency of "worst case" that the particular test represents.

   - The PAMP committee should be responsible for quality assurance of the tracer studies, documenting each test and findings and publishing sufficient volumes of the test description and results so that the results will be available for developers, engineers and environmental scientists.

5. The PAMP committee should quality assure monitoring data, document all quality assurance procedures and publish sufficient volumes of the monitoring documents that developers, engineers and environmental scientists have access to the documents.

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APPENDIX A

MICROMETEOROLOGICAL AIR DISPERSION ASSESSMENT METHODOLOGY (MADAM)

Geothermal Resources Council TRANSACTIONS Vol. 11, October 1987

MICROMETEOROLOGICAL AIR DISPERSION ASSESSMENT METHODOLOGY (MADAM) A GEOTHERMAL AIR QUALITY IMPACT ASSESSMENT TOOLBOX AVAILABLE AS SHAREWARE

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ABSTRACT

The newly completed Micrometeorlogical Air Dispersion Assessment Methodology (MADAM) year long project was funded by the California Energy Commission through the Geothermal Grant Program and was managed by the Lake County Air Quality Management District. The purpose of the project was to develop a verified methodology for geothermal air quality impact assessment for use by regulators, industry and interested groups. The developed and verified methodology reduces the time and effort normally expended in determining geothermal air quality impacts through use of a Personal Computer based program. MADAM is available for interested users cost free as share- ware ($45 registers users for new version announcements) Application, user and reference manuals and assistance are available from GODDARD & GODDARD ENGINEERING. Versions are available for CP/M, PC/MSDOC, Apple IIe (with Applied Engineering Z80 board), and Macintosh PC computers.

PROJECT GOAL

The primary goal of the Micrometeorological Air Dispersion Assessment Methodology (MADAM) project was to develop and document a verified methodology that could be used by the Lake County Air Quality Management District (LCAQMD) staff to quickly, accurately and inexpensively estimate air dispersion pollutant concentrations occurring from a variety of geothermal emission sources in the mountainous Geysers Known Geothermal Resource Area (KGRA).

The developed air dispersion assessment methodology was required to have verified reliability, and be realistic and systematic in evaluating air quality impacts from nearby geothermal emission sources (within a few miles) under slack (low) wind conditions in mountainous settings (complex terrain).

PROJECT PROCEDURES

The methodology was developed, tested and verified using over ten years of excellent and extensive micrometeorological, air quality and tracer data collected in the mountainous Geysers KGRA and the Clear Lake Air Basin.

The MADAM project was conducted by GODDARD & GODDARD ENGINEERING under the direction of the Lake County Air Quality Management District, Robert L. Reynolds, Director and Project Manager John Thompson, Air Quality Engineer. A Guidance Committee was assembled to assist with the project and to ensure that the methodology was scientifically sound and could be used in practical applications. The Guidance committee was comprised of potential users and technical experts, namely: C.E. Woods, (Chairman), Geysers Geothermal Company; Kelly Birkinshaw, California Energy Commission; Mike Cale, GEO Operator Corporation (GRI); Mark Dellinger, Lake County Geothermal Coordinator; Dr. Paul Gudiksen, Lawrence Livermore Laboratory; Matt Haber, Environmental Protection Agency; Ron Knierim, Sacramento Municipal Utility District; Andy Ranzieri, California Air Resources Board; Robert Reynolds, Lake County Air Quality Management District, Director; Steve Sharp, Sonoma County Geothermal Coordinator; Ron Suess, Pacific Gas and Electric Company; Michael Tolmasoff, Northern Sonoma County Air Pollution Control District, Director; and Bob Swan, Mendocino County Air Pollution Control District, Director replaced by Robert Wallen, Mendocino Community College.

The project was approached by dividing the work into five tasks, each of which was defined with a statement of how it was to be accomplished and an approximate time allocated. The work in each task and the results obtained were then presented as a written report and as an oral presentation with illustrations to the Guidance Committee. Each Task Report included appropriate graphs, tables, maps and references. The Guidance Committee members responded with their comments and suggestions. There were, therefore, five Guidance Committee meetings and Five Task Reports. At the fourth Guidance Committee meeting, GODDARD & GODDARD ENGINEERING presented to the LCAQMD an administrative version of MADAM including the computer program. Several useful suggestions were made at this time and incorporated into the version 1.0 of MADAM.

Quarterly reports describing the project's progress and copies of each of the five Task Reports and the Project Final Report were submitted to the California Energy Commission's Project Manager, Kelly Birkinshaw. The project commenced in January of 1986 and a Final Report was submitted to the CEC on March 20, 1987.

ACCOMPLISHMENTS

The MADAM project has developed a Personal Computer-based methodology for rapid and accurate assessment of concentration of air pollutants, at ten selected locations (receptors), which are the result of a single emission (pollution) source. MADAM was developed for use in all terrain settings including mountains, valleys, bluffs and flat plains. Plume rise is estimated for various types of emission sources including steam, cooling towers and other gaseous releases. Atmospheric stabilities ranging from extremely unstable through extremely stable are selected for use in estimating plume rise and air dispersion concentrations. The description of the emission source, the weather conditions, the ten receptors and respective elevations are entered by the user, and stored on computer disk files. For another application these files may then be retrieved, the values for any of the 86 input variables modified, and the new variable values stored under a new application name. All algorithms are adjusted within the computer program for their respective elevation, temperature, humidity and wind speeds. All air dispersion concentration estimates are accompanied with an engineering error estimate which indicates their calculated +/- uncertainty. The methodology is restricted to applications where the emission source is near to the receptors (within 10 miles) under slack (less than 10 mph) wind speeds.

The LCAQMD staff has been supplied with the MADAM version 1.0 computer program, and the methodology's Application, User and Reference Manuals. The staff has been trained in a number of MADAM applications and user supported training sessions are planned for the future. This implementation is for the Apple IIe using an Applied Engineering Z80 board. Other MADAM implementations for Apple IIe (with Z80), Macintosh, PCDOS, MSDOS and CP/M personal computers are are available through GODDARD & GODDARD ENGINEERING.

It is expected that appropriate use of MADAM will result in benefits to state and local governmental agencies, industry and the general public, including:

- making the permitting process more timely by allowing rapid and accurate assessment of air quality impacts;
- protection of public health by allowing prompt, accurate assessment of air quality impact, especially in those cases where geothermal activity has grown into populated areas;
- facilitate the prompt and inexpensive permitting of small size (12.5 megawatt) "drop in place" geothermal electric power plants; o more optimal utilization of the available air and geothermal resources and avoidance of those weather conditions leading to severe air quality impact events through geothermal activities management;
- prompt and timely air quality impact assessment in the site selection planning process; and
- avoidance of the need for time consuming and expensive tracer tests and sophisticated numerical air quality impact modeling.

MADAM USER SUMMARY OUTLINE
OUTLINE OF THE MADAM METHODOLOGY

INTRODUCTION

MADAM is a single source, multiple receptor air dispersion methodology. If multiple sources are involved such as when a cumulative air quality impact analysis is conducted, then MADAM is applied to each emission source and the results are added at the selected receptors. The source emission may be gaseous and/or particulate emanating from steam, cooling towers or other sources. Particulate matter in emissions are assumed to be small enough so that they have insignificant settling velocities.

STEPS IN THE MADAM METHODOLOGY

1. Source Plume Characterization - all factors affecting plume rise are described as input parameters to the MADAM computer program. Input parameters include: exit stack height, source stack diameter, temperature of the emission, cooling tower diameter and number, molecular weight of

emissions, source steam flow rate, non-steam flow rate, atmospheric pressure, source elevation and reference wind speed, temperature and humidity.

2. Determine the Meteorological Conditions for the source area by review and assembly of all meteorological and climatological data, tracer and other dispersion-related studies available for the area.

3. Topographic Analysis - the topography of the area is studied and maps drawn of all significant features such as mountain peaks and ridges, canyons, steepness of slopes and their compass orientation (aspect), valleys, bluffs and cols noted. All pollution emissions sources and receptors of interest are identified on these maps.

4. Flow Paths of Mesoscale and Local Winds, pertinent to the area of interest are drawn from available data sources on the topographic area map. Maps of estimated wind regimes are drawn for each important type such as night-early morning drainage winds (katabatic) and daytime upslope/upvalley winds (anabatic). The predominance of meteorological features such as marine air intrusion, lake or ocean shore breezes, or river basin local wind developments are shown on these maps.

5. Trajectory Paths are estimated and drawn on each wind regime map of the area for each emission source. Distances are measured and recorded from each emission source along each estimated plume path to a line at right angle to each receptor of interest. At each receptor, the horizontal distance from the receptor location to the plume center line is measured and recorded. This approach constitutes the best estimate of the most probable air quality impact. It is important to consider possible conditions which may cause more severe air quality impacts termed "Worst Case" scenarios. These include a case for mountainous terrain plume impingement where elevated pollutants are lofted to the ground. While plume impingement may occur infrequently, the existence of elevated temperature inversions constrained by topographic features such as valley sides, bluffs or mountain sides can force elevated plumes to the ground. In the Worst Case scenario, it is assumed that pollutants could move in near straight line distances even though the necessary wind patterns may occur infrequently. Worst case scenarios are most suitably presented in tabular form with all assumptions clearly stated.

6. Use of the MADAM Computer Air Dispersion Program can now begin with the selection of the input parameters developed from items 1. through 5. The first MADAM menu prompts for a file of input paramenters. User selections are shown in the following as <> containing the first letter of the choice.

MADAM OPENING MENU

****
ENTER COMMAND <>

<F>ilename WHEN NO CHANGE TO INPUT PARAMETER VALUES NEEDED

<C>hanges CHANGE NEEDED TO INPUT PARAMETER VALUES

<M>anual ENTRY OF INPUT PARAMETER VALUES WHEN NO FILE EXISTS
****

The MADAM program has 86 input parameters which can be specified and stored in an input disk file. Manual entry may be selected by <M>anual although it is often easier to change a similar application input file and then store it under a new file name. If changes are necessary to a file then select <C>hanges. The changes may be stored under a new filename when the user has completed the changes. Select <F>ilename when no changes to the input file is necessary since this then skips the input change menus. If <C>hange or <F>ilename are selected, the user is then prompted for a filename.

FILE NAME PROMPT

ENTER <FILENAME> AND RETURN

The user must enter a valid file name which is on the specified disk drive. If <C>hanges are specified, the input file will be displayed in a series of screens that the user may alter. At the bottom of each input parameter list, a prompt will appear requesting the index number of the parameter that the user wishes to change.

PARAMETER INDEX CHANGE PROMPT

****
ENTER NUMBER - <1 THROUGH 18> FOR VALUE CHANGE, OR <RETURN> FOR DONE

To change an input parameter value, the user enters the Index Number and presses <Return>. The input parameter name and present value appears at the screen bottom. The user then enters the new value and presses <Return>. The new parameter value then appears in the input parameter listing. The user continues to make changes until all of the desired changes are made to that screen. When the user is ready to see the next screen of input parameters, <Return> is entered without an Index Number and the next screen is displayed.

INPUT PARAMETER LIST 1 THROUGH 18

Emission Source and Meteorology

The first 18 input parameters of MADAM describe the emission source and the meteorological conditions occuring during plume transport. MADAM makes all necessary corrections for the altitude of the source and meteorological conditions aloft. Each input parameter is described in the following:

MADAM INPUT PARAMETERS 1 THROUGH 18

SOURCE AND METEOROLOGICAL CONDITIONS

INDEX	MADAM INPUT PARAMETER
[1]	Source Stack Height, ft Height at which emissions are released by the source.
[2]	Source Stack Diameter, ft Diameter of source emission release point.
[3]	Source Stack Exit Temperature, F Temperature of source emissions.
[4]	Source Cooling Tower Diameter, ft Diameter of cooling tower exhaust.
[5]	Source Number Cooling Tower Cells Number of cooling tower exhaust fans.
[6]	Source Cooling Tower Exit Velocity,fps Cooling tower exhaust fan exit velocity.
[7]	Source Molecular Weight Exiting Gas, g Average molecular weight of source emissions (Air= 29, Steam= 18).
[8]	Source Steam Flow Rate Exiting, lb/hr Flow rate of steam source emission.
[9]	Source Pollutant Emission Rate, lb/hr Pollutant source emission flow rate - gas or particulates.
[10]	Other Source Flow Rate, cfm Source emissions flow rate other than steam or cooling towers.
[11]	Sea Level Atmospheric Pressure, inHg Standard Sea Level = 29.9 inHg
[12]	Source Elevation, ft Source ground level elevation above sea level.
[13]	Reference Wind Speed, mph Surface wind speed at source and along plume path.
[14]	Surface Roughness Coefficient, ft Typical values are selected from the following:

SURFACE ROUGHNESS COEFFICIENT

Surface,	Height ft,	Roughness ft.
Forest	18	9.3
Orchard Trees	11	6.5
Large City		5.4
Corn Fields	9.8	4.2
Brush	3.0	0.3
Cereal Crops	2.0	0.72
Grass	0.6	0.2
Rough Water		0.06
Smooth Ground		0.0001
Smooth Water		0.0001
Pavement		0.0001

INDEX	MADAM INPUT PARAMETER
[15]	Reference Temperature, F Surface air terperature at source and along plume path.
[16]	Capping Temperature Inversion Height, ftagl Height at which plume's upward dispersion is trapped.
[17]	Reference Relative Humidity, decimal Surface relative humidity at source and along plume path.
[18]	Height Of Meteorological Reference Data, ft Instrument height at which reference conditions specified.

INPUT PARAMETER LIST 19 THROUGH 58

Receptor Description

The next 40 input parameters of MADAM describe the position of each of the 10 selected receptors in relation to their respective distance along the plume path from the emission source, their respective elevation, their respective horizontal distance away from the plume path center line and their respective height at which the pollutant concentration is to be estimated.

INPUT PARAMETERS 19 THROUGH 58

RECEPTOR 1 THROUGH 10 DESCRIPTION

INDEX	MADAM INPUT PARAMETER
[19]	Receptor 1 Plume Path Distance, mi Distance along plume path from the emission source to a line from Receptor 1 normal (at right angle) to the plume path.
[20]	Receptor 1 Elevation, ft Surface elevation above sea level at Receptor 1.

[21] Receptor 1 Plume Horizontal Distance, ft
Horizontal distance from Receptor 1 normal (at right angle) to the plume path.

[22] Receptor 1 Height Above Ground Level, ft
Height above ground at Receptor 1 which pollutant concentration is to be estimated.

[23] through [58] similar for Receptors 2 through 10.

INPUT PARAMETER LIST 59 THROUGH 79

<u>MADAM Air Dispersion Pollutant Concentration Isopleths</u>

Pollutant concentration isopleths data are calculated by MADAM for the General and for the Complex Terrain dispersion applications. The user is required to input the surface elevation along the plume path and the height above the ground at which the isopleths are to be calculated. The user also specifies the 10 desired pollutant concentration isopleths in hourly average parts per billion (ppbv) at which the horizontal distance from the plume center line is to be calculated.

INPUT PARAMETERS 59 THROUGH 79
POLLUTANT CONCENTRATION ISOPLETHS

<u>INDEX</u> <u>MADAM INPUT PARAMETER</u>

[59] Elevation At 0.25 Mile Along Plume Path, ft
Surface elevation below plume path at 0.25 mi from the source.

[60] Elevation At 0.50 Mile Along Plume Path, ft
Surface elevation below plume path at 0.50 mi from the source.

[61] Elevation At 1.0 Mile Along Plume Path, ft
Surface elevation below plume path at 1.0 mi from the source.

[62] Elevation At 1.5 Miles Along Plume Path, ft
Surface elevation below plume path at 1.5 mi from the source.

[63] Elevation At 2.0 Miles Along Plume Path, ft
Surface elevation below plume path at 2.0 mi from the source.

[64] Elevation At 2.5 Miles Along Plume Path, ft
Surface elevation below plume path at 2.5 mi from the source.

[65] Elevation At 3.0 Miles Along Plume Path, ft
Surface elevation below plume path at 3.0 mi from the source.

[66] Elevation At 4.0 Miles Along Plume Path, ft
Surface elevation below plume path at 4.0 mi from the source.

[67] Elevation At 5.0 Miles Along Plume Path, ft
Surface elevation below plume path at 5.0 mi from the source.

[68] Elevation At 6.0 Miles Along Plume Path, ft
Surface elevation below plume path at 6.0 mi from the source.

[69] Isopleth Height Above Ground, ftagl
Height above the ground at which the isopleth concentration estimate is to be calculated.

[70] Isopleth Concentration 1, ppbv
Lowest value of desired pollutant concentration isopleth, for example 4 ppbv.

[71] Isopleth Concentration 2, ppbv
The next desired pollutant concentration isopleth, for example 8 ppbv.

[72] Isopleth Concentration 3, ppbv
The next desired pollutant concentration isopleth, for example 12 ppbv.

[73] Isopleth Concentration 4, ppbv
The next desired pollutant concentration isopleth, for example 16 ppbv.

[74] Isopleth Concentration 5, ppbv
The next desired pollutant concentration isopleth, for example 20 ppbv.

[75] Isopleth Concentration 6, ppbv
The next desired pollutant concentration isopleth, example 24 ppbv.

[76] Isopleth Concentration 7, ppbv
The next desired pollutant concentration isopleth, for example 28 ppbv.

[77] Isopleth Concentration 8, ppbv
The next desired pollutant concentration isopleth, for example 32 ppbv.

[78] Isopleth Concentration 9, ppbv
The next desired pollutant concentration isopleth, for example 36 ppbv.

[79] Isopleth Concentration 10, ppbv
Highest value of desired pollutant concentration isopleth, for example 40 ppbv.

INPUT PARAMETER LIST 80 THROUGH 81

<u>MADAM Valley and Bluff Applications</u>

The Valley and Bluff MADAM applications are used when the valley or bluff sides impede plume horizontal dispersion. The Valley width or the distance to the Bluff from the plume center line are input parameters for these applications.

INPUT PARAMETERS 80 AND 81 VALLEY WIDTH AND BLUFF DISTANCE

INDEX MADAM INPUT PARAMETER

[80] Distance Across Valley , mi
Distance across the valley along which the plume path follows.

[81] Distance To Bluff, mi
Distance from plume path center line to the Bluff.

INPUT PARAMETER LIST 82 THROUGH 86

Estimation of Errors
MADAM Dispersion Estimates

All of the air dispersion estimates made by MADAM are accompanied by a +/- value. This value is a calculation of the 68% probability, assuming random and normally distributed errors, that the MADAM estimate lies between those +/- bounds. Percentage uncertainties are user inputs for the following dispersion variables:

INPUT PARAMETERS 82 THROUGH 86
ASSIGNMENT OF PARAMETER UNCERTAINTIES

INDEX MADAM INPUT PARAMETER

[82] Source Pollutant Emission Rate Uncertainty, decimal
Percentage error estimate of uncertainty in the pollutant emission rate.

[83] Wind Speed Uncertainty, decimal
Percentage error estimate of the uncertainty in the reference wind speed.

[84] Horizontal Dispersion Coefficient Uncertainty, decimal
Percentage error estimate of the uncertainty in the horizontal dispersion coefficient Sigma Y.

[85] Vertical Dispersion Coefficient Uncertainty, decimal
Percentage error estimate of the uncertainty in the vertical dispersion coefficient Sigma Z.

[86] Plume Rise Height Uncertainty, decimal
Percentage error estimate of the uncertainty in the plume rise height estimate.

USER PROMPT FOR NEW OR OLD INPUT FILE NAME

Upon completing the changes desired to the MADAM input parameters, a menu will appear requesting a new file name or an option for the changes to be stored in the original file.

```
****************************************
EITHER ENTER NEW <FILENAME> AND  PRESS
      RETURN FOR NEW DISK FILE

OR ENTER <F>inished FOR PARAMETER DISK
      FILE IN ORIGINAL FILENAME
****************************************
```

If the user desires to store input parameter changes under the original file name then select <F>inished. For a new file name enter the new file name then <RETURN>. The file name convention allows 8 letters followed by a 3 letter prefix (for example, POWERPLT.IPT) If the input file was entered manually, then the prompt will only include a request for a file name.

EMISSION SOURCE TYPE SELECTION

The user is asked to select either <S>team, <C>ooling Towers or <O>ther from the list of Emission Sources.

```
****************************************
        PLUME RISE CALCULATIONS
          SELECT  DESIRED  CASE
****************************************
     SELECT TYPE OF EMISSION SOURCE
             ENTER COMMAND
<S>team, <C>ooling Tower, <O>ther Source
****************************************
```

ATMOSPHERIC STABILITY SELECTION

The user is requested to choose the Pasquil Atmospheric Stability Class A through G. The atmospheric stability classes are described by typical examples of temperature profiles aloft and typical horizontal wind direction standard deviation, Sigma. A typical day will begin with stable conditions in the early morning followed by neutral in mid morning then unstable through late afternoon. Neutral will again occur in the early evening with increasing more stabile conditions throughout the night. The relationship between weather conditions and stability classification are described in the following:

RELATIONSHIP OF ATMOSPHERIC STABILITY CLASSES TO WEATHER CONDITIONS

CLASS	CLASS
A - Extremely Unstable Conditions	D - Neutral Conditions *
B - Moderately Unstable Conditions	E - Slightly Stable Conditions
C - Slightly Unstable Conditions	F - Moderately Stable Conditions
	G - Extremely Stable Conditions

Surface Wind peed, mph	Daytime Sunlight Strong	Moderate	Slight	Nighttime Conditions Cloud Cover** >= 1/2	< 3/8	Clear
< 4.5	A	A-B	B	E	F	G
4.5	A-B	B	C	E	F	G
9.0	B	B-C	C	D	E	F
13	C	C-D	D	D	D	E
> 13	C	D	D	D	D	D

* Applicable to heavy overcast and marine intrusion, day or night

** Cloudiness is defined as that fraction of the sky above the local horizon which is covered by clouds.

The selection is made by the user of a stability class <A> through <G> from the following menu:

ATMOSPHERIC STABILITY CLASSIFICATION

SELECT DESIRED CLASS

```
*************************************************************************
ENTER COMMAND -  Select Atmospheric Stability Classification

 Atmospheric Stability        Typical Temperature Gradient       Wind Sigma
        Class                   C / 100 m          F / 1000 ft      Degrees
<A> - Extremely Unstable        < - 1.9             < - 17.5          25
<B> - Moderately Unstable  - 1.9 to <- 1.7   - 10.4 to <- 9.3         20
<C> - Slightly Unstable    - 1.7 to <- 1.5    - 9.3 to <- 8.2         15
<D> - Neutral              - 1.5 to <- 0.5    - 8.2 to <- 2.7         10
<E> - Slightly Stable      - 0.5 to <  1.5    - 2.7 to <  8.2          5
<F> - Moderately Stable      1.5 to <  4.0      8.2 to <  22          2.5
<G> - Extremely Stable         > = 4.0            > = 22            < 2.5
*************************************************************************
```

MADAM REPORT SELECTIONS

MADAM Output Reporting Selection Menu

The <S>creen selection refers to reporting results on the computer console only with no recorded record. The <P>rinter selection allows a hard copy to be printed immediately. The <T>ext File option writes results to an ASCII disk file for later printing or word processing. The Text file option is followed by a prompt requesting a file name. The Printer and Text file options report all results also to the computer console. The Printer and Text file options both record the MADAM input parameters as well as the MADAM results. After the user selects the desired mode of reporting, MADAM will proceed with the report.

MADAM REPORTING MODE SELECTION MENU

```
***************************************
SELECT DESIRED MODE FOR MADAM OUTPUT

ENTER COMMAND - OUTPUT TO   <S>creen,
        <P>rinter,   <T>ext File
***************************************
```

MADAM PLUME RISE REPORT

The plume rise report lists the type of emission source and the stability condition. The buoyancy plume rise is listed above ground level. Additional plume rise occurs due to the heat of condensation from moisture and is listed as a percent. The jet effect of the released emission source is listed as the momentum plume rise. The conditions aloft which are calculated from the surface reference conditions are listed as the average wind speed and temperature aloft. The reference wind speed and temperature are also listed.

MADAM CASE SELECTION

Selection of the desired MADAM application case depends upon the topographical terrain features. The <G>eneral case is intended for gently rolling and flat topography or for cases where the plume follows the terrain features. The <C>omplex Terrain case is intended for mountainous terrain where plume impingement may occur. The <V>alley case is intended for situations where the valley sides impede plume dispersion. The <B>luff case is intended for cases where a bluff impedes plume dispersion. The <F>umigation case is intended for situations where pollutants disperse into stable air and then are later mixed to the surface receptors.

MADAM REPORT LENGTH

The user may select from the MADAM reporting selection menu an <A>bstract summary or <F>ull report on each of the 10 receptor locations.

MADAM <F>ull reporting output lists the Receptor distance along the plume transport path and the pollutant concentration above ambient in ug/m**3 which is then converted, using the Receptors elevation and temperature, to ppbv. Hourly conversions are listed where the MADAM few minute average is multiplied by 0.61 to convert to an hourly average. The remaining details of the estimate include the receptor elevation, the inversion height, the distance from the receptor along a normal line to the plume path, the height at which the pollutant concentration was calculated, the stack level wind speed and the Gaussian dispersion coefficients Sigma Y and Sigma Z.

An <A>bstracted hourly summary reporting is available to the user who does not want all of the information contained in full reporting.

If longer averaging times are desired, the concentration estimates of MADAM may be multiplied by the following:

ACKNOWLEDGEMENT

We appreciate the able assistance of William R. Knuth, Meteorologist, on the MADAM project.

AVERAGING TIME VERSUS MADAM ESTIMATES

AVERAGING TIME	MULTIPLY MADAM ESTIMATE BY
3 TO 10 MINUTES	1.0
15 MINUTES	0.82
1.0 HOUR	0.61
3.0 HOURS	0.51
24 HOURS	0.36

Note: Hourly averages reported by MADAM have been obtained by multiplying by 0.61.

MADAM POLLUTION CONCENTRATION ESTIMATES ISOPLETHS

The user has the choice of <G>eneral or <C>omplex Terrain isopleths of concentration, or <N>o for program end.

Each of ten locations are reported from which isopleths of the selected hourly ppbv concentrations may be plotted. Each of the 10 locations, 0.25, 0.50, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 5.0 amd 6.0 mi, are reported separately. The isopleth report lists the height at which estimates were calculated as 32.8 ft (10 m) above the surface. The plume center line hourly concentration, above ambient, at this height is listed in ppbv. The horizontal distance normal to the plume centerline out to the desired isopleth is listed for ten user selected intervals such as from 4 to 40 ppbv.

From the isopleth report of the ten locations along the plume path, the user can plot the distance normal to the plume path center line out to each desired concentration isopleth. Interconnection of these points for each of the selected hourly above ambient concentrations produces an isopleth for each desired concentration.

CONCLUSION

This concludes the condensed summary of MADAM features. We encourage all interested parties to obtain a copy and use the methodology to assist them in their air quality impact assessment needs.

All those interested in a training seminar on MADAM which will be conducted late summer or early fall are encouraged to contact GODDARD & GODDARD ENGINEERING.

APPENDIX B

KS8 WELL VENTING HEALTH COMPLAINTS AND SYMPTOMS DATA

ACKNOWLEDGEMENTS

Big Island Rainforest Action Group ... Printed and distributed surveys in the communities affected and collected completed forms

Colleen Mandala ... Pahoa Natural Foods -- circulated a health survey compiled by a medical doctor and collected responses from area residents

Kapoho Community Association ... mapped locations of affected residents from health surveys
-- plotted possible wind flow
-- collated health surveys into statistical data for each subdivision or area impacted

HEALTH SURVEY SUMMARY FROM BIRAG AND PAHOA EMPORIUM QUESTIONNAIRES FOR KS-8 BLOWOUT OF JUNE 12, 1991.

CODE NO.	SUBDIVISION NAME	NO. OF FORMS
1	Puu Honuaula	4
2	Lanipuna	12
3	Pohoiki Bay Estates, Leilani	37
4	Opihikao Homesteads	12
5	Puna Palisades	3
6	Kehena	4
7	Kalapana Seaview Estates	9
8	Black Sands Subdivision .	8
9	Upper Kaimu Homesteads	1
10	Kamaili Homesteads	4
11	Kaoho	3
12	Ainaloa, Orchidland	2
13	Hawaiian Acres	2
14	Hawaiian Paradise Park	4
15	Hawaiian Beaches, Hawaiian Shores	2
16	Pahoa, Nanawale	9
17	Kapoho	7

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Odor of Sulfur	4	11	29	11	2	4	9	5	1	4	2		1	3	1	6	4
Loss of Smell/Taste		2	3			1											
Eye Irritation	5	10	26	8			3	4	1	1	3		1	4	2	4	2
Nose Irritation	1	4	9	1			1	1			2			2		1	2
Throat Irritation	6	10	19	7	1	3	7	2		4	3	1	1	4	2	4	3
Trouble Breathing	3	5	11	8		2	5	2		2	2	1		2		3	2
Coughing Wheezing	2	5	11		1			1			1			2			1
Hyperexcitability	2	1	2					1									
Insomnia/ Trouble Sleeping	1	4	8	2	1			1		1	2	1	1	1		2	
Headaches	6	9	27	10	3	2	6	4		3	3	1	2	4	1	6	4
Earaches	2	1	4	1			1	1						1			2
Dizziness	5	6	14	3		1	4	1				1		2		4	4
Loss of Balance/		1	5					1									
Staggering														1			
Weakness	1	3	8	1	1			1			1						
Rash/Skin Irritation	8	2	5	2		1	1	1		1	1	1	1				1
Hair Loss			2														
Joint or Muscle Pain		3	5		1		1	1						1			
Nausea	2	4	7	1	1		1	1			2			2			2
Upset Stomach	1	8	9	5	1	2	5	2	1		1	1		1		5	
Vomiting	1	2	3				1	1				1		1			
Diarrhea		2	6				1	1						1			
Loss of Appetite	1	2	5		1			1						1			1
Weight Loss		1	2				1							1			
Low Blood Pressure																	
Anxiety	2	6	13	2			1	2	1		1					1	2
Panic Attacks	2	1	7	2				2			1						1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Lethargy/No Energy/ Sluggish	1	3	8	1	1			1			1			2			1
Heart Palpitations	1	1	2												1		
Chest Pains	1	1	6											1	1		
Shortness of Breath	1	1	7	1				1			1			1			1
Seizures			1														
Coughing up Blood			1														
Blood in Urine/Stool			1				1				1						
Sulfur Odor in Urine /Stool	1																1
Irregular Mensis	1	1	3					1									
Fever			1											1			1
Mucous		1	2														
Medical Care	1	3	3	1							1			1			1
Heard venting noise	4	8	20	12	2	3	8	6	1	4	2	2	1	2	1	8	3
Noise irritating	4	8	20	11	2	2	8	6	1	4	2	2	1	2	1	7	2
Water catchment	4		20	12	2	4	8	6	1	4	2	2	1	2		3	4
Fallout on roof	2	3	6	2		1	1	2		1	1					4	1
Car damage	2	1	1													1	
Animals/Plants	4	4	6				2				1						

OTHER COMMENTS:

Nightmares (Opihikao, Nanawale

Gray spots on clothing in Leilani on 6/13 12:30 pm

Two weeks of illness from driving by plant twice in one day.

One child had fever and numb right side (leg & arm). Nohea St.

Whenever husband smells sulfur he vomits. Was worse with HGPA leaks. Feel weak a lot. Mohala St.

Dead bird, dying butterflies (Nanawale

Birds left. Opihikao

No officials able to tell about effect on water catchment. Came home on 6/16. Hookupu St.

Average 80 dba for 30 hours. Pohoiki Bay Estates

Dogs howling all night. Nohea St.

I can't believe that Puna is in America. Leilani Ave.

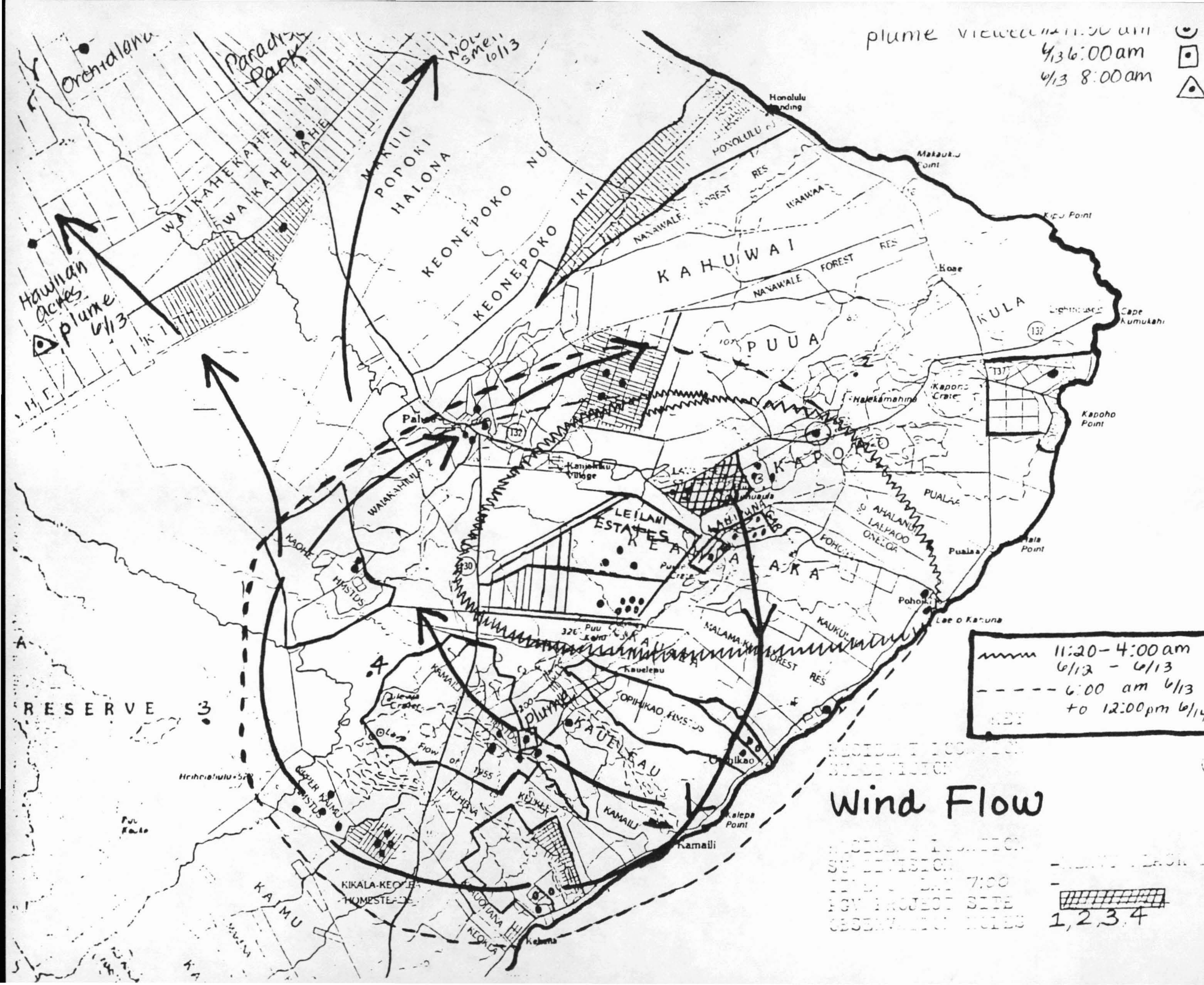
Chickens staggering. Puu Honuaula

Eye Infections, extreme fear/acting crazy. Animals vomiting and acting weird. Puu Honuaula

Vomit, diarrhea. black feces, eyes shut tight with mucuous. Puppy's stool bloody and projectile, died by end of day. During abated vent felt sluggish, drifting off, not concentrating; mouth feels strange, taste is gone, get light throaty cough, stomach feels floaty (maybe vomit, maybe not), caustic soda smell can give a headache in minutes. Hinalo St.

Swollen and sore glands in throat and arm pits 5 year old child. Hinalo

Depression, crying over 24 hours. Dogs lethargic, not eating. Still have a feeling of fear and no peace in our own home. Hinalo St


plume viewed 11:30 am
6/13 6:00 am
6/13 8:00 am
Orchidland
Paradise Park
No smell 6/13
Hawaiian Acres plume 6/13
WAIKAHEKAHE NUI
WAIKAHEKAHE IKI
MAKUU
POPOKI
HALONA
KEONEPOKO NUI
KEONEPOKO IKI
Honolulu Landing
HONOLULU
NANAWALE FOREST RES
WAAWAA
KAHUWAI
NANAWALE FOREST RES
Kapu Point
Kaoe
KULA
Cape Kumukahi
PUUA
Kapoho Crater
Halekamahina
Kapoho Point
Pahoa
Kaniahiku Village
KAPOHO
LEILANI ESTATES
KEAAU
WAIAKAHIULA 2
KAOHE
HMSTDS
PUALAA
AHALANUI
LAEPAOO
ONELOA
POHOIKI
MALAMA-KI FOREST RES
KAUKULAU
Pohoiki
Lae o Kahuna
Puu Kalo
Kauelepu
OPIHIKAO HMSTDS
KAUELEAU
KAMAILI
KEHENA
Kalepa Point
Kamaili
Opihikao
RESERVE
KIKALA-KEOKEA HOMESTEADS
KAMU
KEOKEA
Kehena
Kaueleau Crater
Lava Flow of 1955
plume
11:20 – 4:00 am 6/12 – 6/13
6:00 am 6/13 to 12:00 pm 6/14
Wind Flow
1, 2, 3, 4

APPENDIX C

OPERATIONAL MANAGEMENT OF AIR RESOURCES

(OMAR)

Geothermal Resources Council TRANSACTIONS, Vol 14, Part II, August 1990

AIR QUALITY COMPLIANCE IMPROVEMENTS THROUGH OPERATIONAL MANAGEMENT OF AIR RESOURCES (OMAR)

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ABSTRACT

Geothermal well fields and power plants require operational and emergency atmospheric venting. Venting activities are monitored for compliance with regulations which limit air pollutant emissions and Ambient Air Quality Standards (AAQS). Continuous compliance monitoring data which includes hydrogen sulfide (H2S) levels and meteorological conditions is only available months after being compiled.

An automated computerized system called OMAR is described in the following which checks data and allows users access to real-time and near real-time data reports. The data can then be used for managing necessary venting or other real-time data needs.

The OMAR system hardware and software is described and is in use at The Geysers and at the Coso KGRA geothermal developments in California. The system has been designed to assist developers, engineers, scientists, and the local air districts in their goal of maintaining ambient air quality within Federal, State and Local standards.

INTRODUCTION

In the spring of 1987, Goddard & Goddard Engineering (G&GE) proposed the project termed OMAR which would develop an automated computerized system to check real-time data and make available to users near real-time data reports. It was proposed that the OMAR project be managed by the Lake County Air Quality Management District (LCAQMD) and funded by the California Energy Commission's (CEC) Geothermal grant program. A formal contract was signed by G&GE on May 23, 1988 to begin work on the project.

A similar OMAR project was proposed to the California Energy Company, Inc. (CECI) in the spring of 1988 and final approval was given in November 1989 for the system design and deployment.

The goal of the research and development project was to automate use of air quality and meteorological (aerometric) compliance monitoring data which would then be available for managing necessary geothermal venting operations at The Geysers and at the Coso developments. Participating parties included the LCAQMD, CECI, CEC, the Northern Sonoma County Air Pollution Control District (NSCAPCD), and the Great Basin Unified Air Pollution Control District (GBUAPCD). Automated computer access has been or is planned at LCAQMD, NSCAPCD, GBUAPCD and at the CECI Coso Division headquarters (Goddard, 1989).

While industry has carried the financial costs of these necessary compliance monitoring programs, the data has not been available in real or near real-time. Data reports have only been available on a quarterly basis after months of data auditing and passing thorough quality assurance standards (QA). While QA procedures are necessary, this has not allowed real-time access to these data.

The OMAR project has resulted in allowing users access to the compliance monitoring data for use in managing activities which include necessary venting, planning operations and construction work and specialized studies which require these data.

OMAR SYSTEM DESIGN AND OPERATION

An organizational diagram of OMAR is shown in Figure 1. Aerometric sensors including wind speed, wind direction, air temperature and humidity, precipitation and H2S concentration are monitored by Campbell Scientific Inc. (CSI) data loggers. The CSI data loggers can record up to 5 months of data unattended. The CSI data loggers are programed to collect 3 minute peaks, Sigma (standard deviation of wind direction), hourly averages and running totals for precipitation.

The CSI data loggers are accessed via modems through telephone lines and radio telemetry. The loggers are programed to automatically send an out-of-range alarm data reports to the remote OMAR computer if the 3 minute peak H2S concentration exceeds a decision threshold criteria (nominally 20 ppb). .

Access to the CSI data loggers is initiated from the remote OMAR computer at a short interval (nominally 1 hour), or upon receipt of an out-of range alarm report from one CSI monitoring site or by a local OMAR computer users.

OMAR Hardware and Software Description

The main elements of the OMAR hardware and software components are shown in Figure 2. IBM 386 compatible computers which operate reliably in a true multi-tasking mode are used for local and the remote computers.

The remote computer is installed near enough to the CSI aerometric monitoring sites that efficient and cost effective frequent communication can be obtained. The remote computer is equipped with a CSI clock-SIO and power-up board which turns the computer off and then on again (cold boots) in cases where the computer hangs-up or in cases where communication links become tied-up. This hardware/software equipment is necessary where computers run remotely to avoid manual restarts.

Each participating OMAR user must have a dedicated local computer (or one with multi-tasking capabilities) which is IBM compatible. The local multi-tasking function allows the user to use the computer for running their general purpose programs while the OMAR programs operate in the background.

The software used for this purpose is Quarter Deck's Desqview(1). Desqview can have as many as 9 programs all running at once depending on memory size. Procomm(2) is used by both the remote and local computers to automatically telecommunicate. Two CSI programs Telcom(3) and Split(3), are used timing, coordination and data processing. Quatro(4), a spreadsheet program by Borland International, is used for data graphical display. Several programs which check data and coordinate activities where developed for OMAR. A site-specific version of MADAM is used for the air dispersion assessments (Goddard, 1988).

Functions of the Remote OMAR Computer

The remote OMAR computer serves as a remote node with communication links to each CSI data logger monitoring site and with a communication link to the local OMAR computer users. The functions of the remote OMAR computer are shown in Figure 3.

The remote functions include receiving out-of-range alarm reports from the CSI monitoring sites, compiling out-of-range alarm reports, archiving short term (nominally 1 hour) near real-time data reports and archiving monitoring data in report form. When data is found to be out-of-range an alarm report is immediately sent to each local OMAR computer.

The remote OMAR computer, upon receiving an CSI logger alarm data report, automatically initiates a program which accesses all the OMAR CSI sites and performs an out-of-range data check. If the check finds data out-of-range (nominally 15 ppb 15 minute average), the remote OMAR computer automatically sends an out-of-range alarm report to the local OMAR computers.

The remote computer automatically polls (calls) each CSI monitoring site each hour (nominally) and downloads the last hour's data from each site. An out-of-range data check is made and the data is archived in a short term report and in a long term data archive.

Once a day a 24-hour data summary is sent to each local OMAR computer. These summaries are used to assist in maintaining quality assurance, increased data capture rates and for general operational needs.

Upon receipt of a command from the local OMAR computer, the latest near real-time data report is sent to the local computer. Long term data archives are sent to the local OMAR computer when requested.

Local OMAR Computer Functions

The local OMAR multi-tasking computers can be used to run general purpose programs as well as running OMAR programs in the background. The OMAR functions are shown in Figure 4. Programs automatically answer incoming calls from the remote OMAR computer to receive data reports, alarm reports (which beep on receipt) and long term archived data reports. On command programs display numerical and graphical data reports and perform air dispersion assessments.

OMAR Air Dispersion Assessments

Each OMAR installation has been designed to monitor conditions at and near receptors of concern and at sites of meteorological interest. The system design provides the necessary near real-time data needed to run air dispersion assessments for emission sources of concern.

Ridge top and/or mountain top stations are used to determine the state of atmospheric stability, the presence of marine air intrusion and/or subsidence capping temperature inversions. A station on the Mayacmas Mountain ridge at The Geysers and a station on top of Sugar Loaf Mountain at Coso are used for this purpose.

When a user requests an air dispersion assessment from the local OMAR computer, the first operation that is performed is the retrieval of the latest near real-time data report from the remote OMAR computer. The data is then processed to determine the present meteorological conditions and whether good or poor air dispersion conditions exist.

The user enters the location of the necessary venting operations in UTM coordinates, the elevation and the type of emission source. The OMAR air dispersion program will then estimate the incremental impact of the venting above ambient concentrations of H2S and the cumulative impact base on the monitored ambient H2S levels.

The user can run several venting scenarios including decreases in existing venting from bleeding or testing wells, or other emission sources. While users must obtain local air district permission to surpass venting emission limits, they can use OMAR as a management tool in demonstrating that venting will not result in substantial increased H2S levels.

OMAR will assist in avoiding poor air dispersion impacts when emergency venting break-downs occur. Users can immediately determine what the ambient levels of H2S are and reduce venting of manageable emissions so that impacts are maintained well below AAQS.

SUMMARY AND CONCLUSIONS

The OMAR system allows access in real-time to compliance monitoring data for use in making management decisions concerning necessary geothermal venting operations. The real or near real-time data is coupled to site specific complex terrain air dispersion models to yield impact assessments. The venting impact assessments allow various venting scenarios to be evaluated using actual near real-time air quality and meteorological data.

Decreased ambient air quality throughout the world especially near urban centers has led to agencies increasing the punitive penalties for exceeding emission limits and/or exceeding AAQS. The California Clean Air Act mandates three year attainment (no exceed of an AAQS) before conferring attainment status. Non-attainment areas must provide air quality impact offsets which may not be available and are always expensive.

Geothermal energy has proved itself to be environmental compatible. The geothermal industry in California has proven its ability to operate competitively within the stringent H2S CAAQS of 42 ug/m3 (0.03 ppm) and OMAR enhances this ability.

REFERENCES

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Use of Required Air Compliance Monitoring for Management of Necessary Venting - a Project Initiated at The Geysers - Applications and Development of Operational Management of Air Resources (OMAR), Geothermal Resources Council, TRANSACTIONS Vol 13 Davis, CA

Goddard, W.B. and C.B. Goddard, Oct 1987
Micrometeorological Air Dispersion Assessment Methodology (MADAM), A Geothermal Air Quality Impact Assessment Toolbox Available As Shareware, Geothermal Resources Council, TRANS-ACTIONS, Vol. 11, Davis, CA

Note:
(1) Desqview is a product of Quarter Deck Office Systems, Santa Monica, CA
(2) Procomm is a product of Datastorm Technologies, Columbia, MO
(3) Telcom and Split are products of Campbell Scientific, Logan UT
(4) Quatro is a product of Borland International, Scotts Valley, CA

Goddard, W.B. and C.B. Goddard

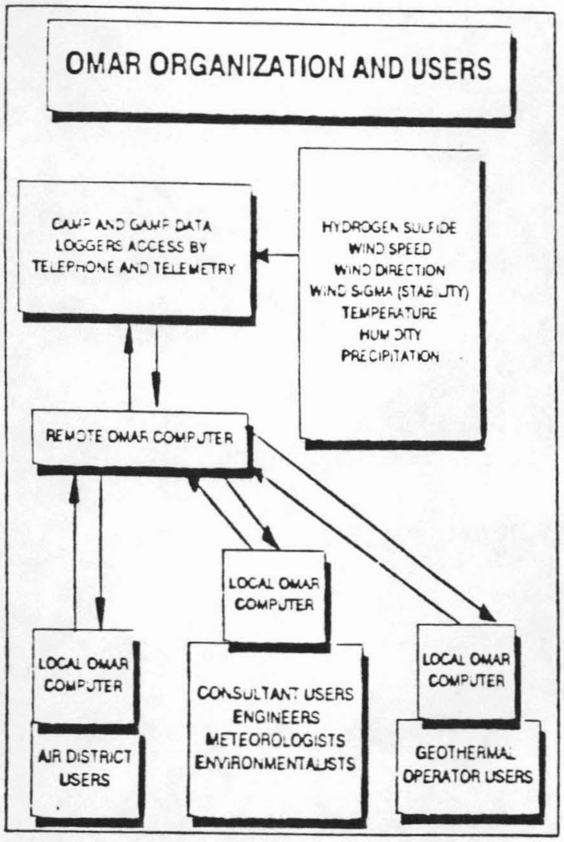

FIGURE 1: OMAR ORGANIZATION AND USERS

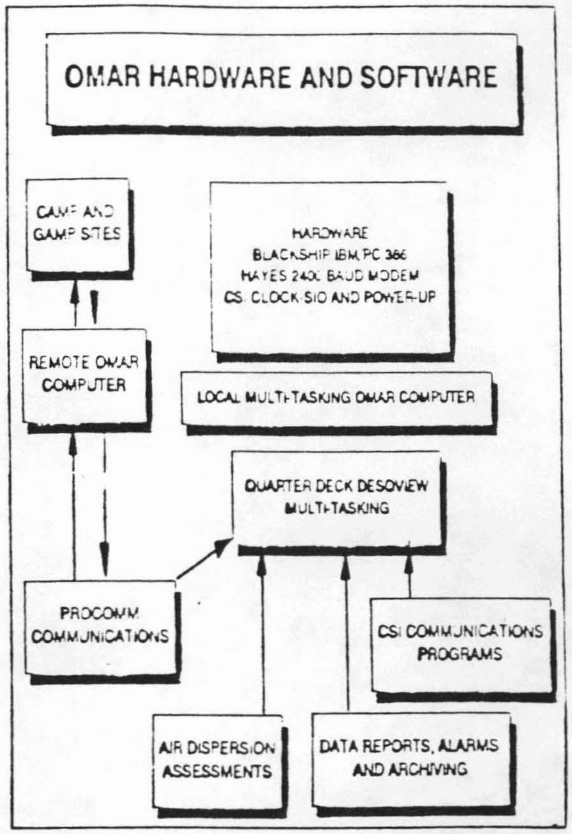

FIGURE 2: OMAR HARDWARE AND SOFTWARE

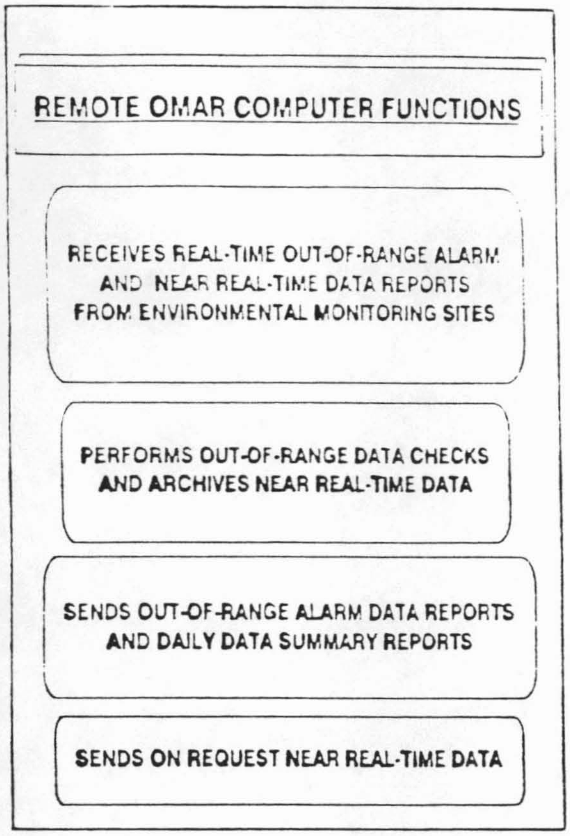

FIGURE 3: REMOTE OMAR COMPUTER FUNCTIONS

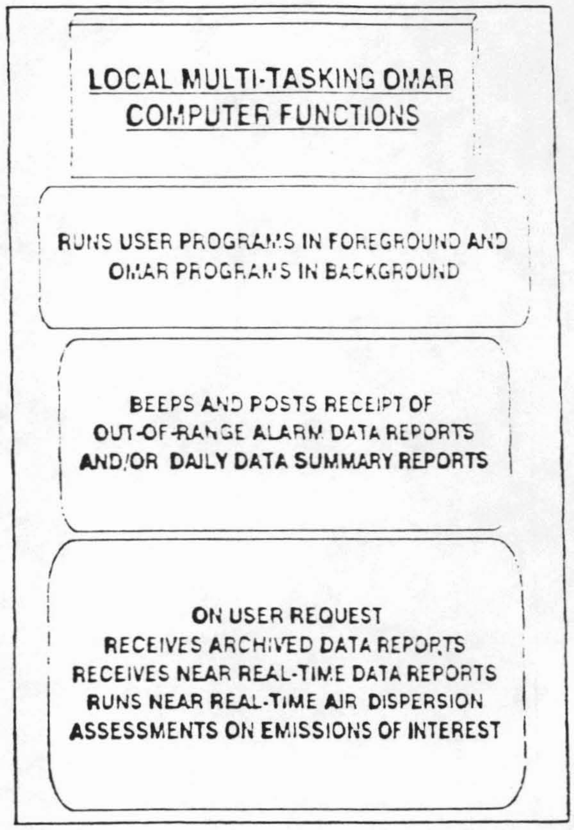

FIGURE 4: LOCAL MULTI-TASKING OMAR COMPUTER FUNCTIONS